UNIVERSIDADE DE LISBOA
FACULDADE DE MEDICINA VETERINÁRIA

SHORT-TERM COMPLICATIONS FOLLOWING A TPLO SURGERY: RETROSPECTIVE STUDY OF 38 CASES

MARION ALMEIDA D'ALCÂNTARA CARREIRA

ORIENTADOR:
Doutor Luís Miguel Alves Carreira

TUTOR:
Dr. Guillaume Ragetly

2021

UNIVERSIDADE DE LISBOA
FACULDADE DE MEDICINA VETERINÁRIA

SHORT-TERM COMPLICATIONS FOLLOWING A TPLO SURGERY: RETROSPECTIVE STUDY OF 38 CASES

MARION ALMEIDA D'ALCÂNTARA CARREIRA

DISSERTAÇÃO DE MESTRADO INTEGRADO EM MEDICINA VETERINÁRIA

JÚRI
PRESIDENTE:
Doutor António José de Almeida Ferreira
VOGAIS:
Doutor Luís Miguel Alves Carreira
Doutor António Manuel Correia Martinho Lopes

ORIENTADOR(A):
Doutor Luís Miguel Alves Carreira
TUTOR:
Dr. Guillaume Ragetly

2021

DECLARAÇÃO RELATIVA ÀS CONDIÇÕES DE REPRODUÇÃO DA DISSERTAÇÃO

Nome: Marion Almeida D'Alcântara Carreira

Título da Tese ou Dissertação: Short-term complications following a TPLO surgery: Retrospective Study of 38 cases

Ano de conclusão (indicar o da data da realização das provas públicas): 2021

Designação do curso de Mestrado ou de Doutoramento: Mestrado Integrado em Medicina Veterinária

Área científica em que melhor se enquadra (assinale uma):

X Clínica ☐ Produção Animal e Segurança Alimentar

☐ Morfologia e Função ☐ Sanidade Animal

Declaro sobre compromisso de honra que a tese ou dissertação agora entregue corresponde à que foi aprovada pelo júri constituído pela Faculdade de Medicina Veterinária da ULISBOA.

Declaro que concedo à Faculdade de Medicina Veterinária e aos seus agentes uma licença não-exclusiva para arquivar e tornar acessível, nomeadamente através do seu repositório institucional, nas condições abaixo indicadas, a minha tese ou dissertação, no todo ou em parte, em suporte digital.

Declaro que autorizo a Faculdade de Medicina Veterinária a arquivar mais de uma cópia da tese ou dissertação e a, sem alterar o seu conteúdo, converter o documento entregue, para qualquer formato de ficheiro, meio ou suporte, para efeitos de preservação e acesso.

Retenho todos os direitos de autor relativos à tese ou dissertação, e o direito de a usar em trabalhos futuros (como artigos ou livros).

Concordo que a minha tese ou dissertação seja colocada no repositório da Faculdade de Medicina Veterinária com o seguinte estatuto (assinale um):

1. X Disponibilização imediata do conjunto do trabalho para acesso mundial;
2. ☐ Disponibilização do conjunto do trabalho para acesso exclusivo na Faculdade de Medicina Veterinária durante o período de ☐ 6 meses, ☐ 12 meses, sendo que após o tempo assinalado autorizo o acesso mundial*;

* Indique o motivo do embargo (OBRIGATÓRIO)

Nos exemplares das dissertações de mestrado ou teses de doutoramento entregues para a prestação de provas na Universidade e dos quais é obrigatoriamente enviado um exemplar para depósito na Biblioteca da Faculdade de Medicina Veterinária da Universidade de Lisboa deve constar uma das seguintes declarações (incluir apenas uma das três):

1. É AUTORIZADA A REPRODUÇÃO INTEGRAL DESTA TESE/TRABALHO APENAS PARA EFEITOS DE INVESTIGAÇÃO, MEDIANTE DECLARAÇÃO ESCRITA DO INTERESSADO, QUE A TAL SE COMPROMETE.
2. É AUTORIZADA A REPRODUÇÃO PARCIAL DESTA TESE/TRABALHO (indicar, caso tal seja necessário, nº máximo de páginas, ilustrações, gráficos, etc.) APENAS PARA EFEITOS DE INVESTIGAÇÃO, MEDIANTE DECLARAÇÃO ESCRITA DO INTERESSADO, QUE A TAL SE COMPROMETE.
3. DE ACORDO COM A LEGISLAÇÃO EM VIGOR, (indicar, caso tal seja necessário, nº máximo de páginas, ilustrações, gráficos, etc.) NÃO É PERMITIDA A REPRODUÇÃO DE QUALQUER PARTE DESTA TESE/TRABALHO.

Faculdade de Medicina Veterinária da Universidade de Lisboa, 22 de Julho de 2021

Assinatura: Marion Carreira

AGRADECIMENTOS

Em primeiro lugar quero agradecer ao Prof. Miguel Carreira por todo o apoio e paciência. O seu vasto conhecimento e a sua exigência, por vezes assustadores, são um grande incentivo para o meu desenvolvimento. Obrigada pela compreensão e motivação!

Un grand merci au Centre Hospitalier Vétérinaire Frégis – CHV pour la possibilité de faire mon stage dans un centre d'excellence. Merci au Dr Guillaume Ragetly pour le support, patience et les magnifiques chirurgies auxquelles j'ai eu la possibilité d'assister. Merci à tous les medecins, chirugiens et ASV formidables que j'ai eu la chance de rencontrer, avec un remerciement special aux internes de Frégis.

Aos fantásticos estagiários Sandrine, Inês, Carolina, Kim e Fábio, que me ajudaram imenso, motivaram e com os quais aprendi imenso. Merci Kim pour ton amitié! Fábio obrigada pelas fotografias excelentes de qualidade profissional!

A todos os meus colegas de trabalho na IKEA, em especial Ricardo, Margarida, Sónia, Tony, Mónica, Mafalda, Paula, Daniela e Inês, pelo apoio e por acreditarem em mim!

To all my travel friends – and especially to Katrina, Merick (and Baghy), Sabrina, Ashley Esteban, Pixie and Hiral for your support, friendship, and knowledge. I am so fortunate to have met you all. You inspired me and you showed me a whole different world! Thank you so much!

A todos os meus amigos que estiveram presentes durante este longo percurso. Às amigas Cristina Barroso e Cristina Estevens, pelas horas partilhadas nos telefones, pelos desabafos e conselhos. Às amizades que prevalecem: obrigada Nádia Miguel, sem ti os fins-de-semana teriam sido muito mais difíceis. Às novas amizades que surgem no momento certo: Obrigada Marlene pelos maravilhosos sunsets partilhados à beira-mar!

Especialmente às amigas que conheci durante esta aventura: Catarina, Cátia, Raquel, Didia e Sofia Guedelha. Obrigada pela ajuda e amizade construida ao longo destes anos todos! Catarina sem ti não teria sobrevivido a esta dura provação, a tua amizade, força de vontade e carinho fizeram-me crescer! Cátia, és uma força da natureza! Obrigada por estares sempre presente!

Às irmãs que a vida me dá: Carlota e Sabbi, obrigada pelo vosso amor incondicional!

Às amizades inesperadas da vida, ao meu querido amigo Vini! Obrigada pelo teu apoio nestes meses, por esta amizade sincera e maravilhosa. Pelos pequenos-almoços com panquecas, nutella e croissants!

Aos meus pais, por me apoiarem sempre e por estarem sempre presentes nos bons e maus momentos! Por acreditarem em mim e me incentivarem sempre a crescer! À minha irmã, pelo amor incondicional! Sei que posso sempre contar contigo! À minha grande e maravilhosa família pelo apoio e paciência! À minha avó Chouchou pour l'inspiration et motivation! Ao Luís, por me ter ajudado e apoiado ao longo deste difícil percurso.

À Dada, merci pour ton amitié et support pendant mon stage! Merci cousine, sans toi ça n'aurait pas été possible!

E finalmente, à minha prima Inês, por me teres ensinado o significado de Coragem e Perseverança!

RESUMO

COMPLICAÇÕES A CURTO PRAZO APÓS CIRURGIA TPLO:
ESTUDO RETROSPECTIVO DE 38 CASOS

A rotura do ligamento cruzado cranial é uma das causas mais comuns de claudicação do membro pélvico em cães e a sua etiopatogenia não está ainda completamente conhecida. Trauma pode ser a causa para uma lesão aguda do ligamento, contudo a maioria dos casos parece resultar de alterações degenerativas crónicas no ligamento. O tratamento cirúrgico é normalmente o tratamento de eleição, para minimizar a instabilidade da articulação e a progressão da doença degenerativa articular. Apesar das técnicas intra e extra capsulares apresentarem bons resultados, as osteotomias tibiais são geralmente preferidas. A cirurgia *tibial plateau levelling osteotomy* (TPLO) tem como objectivo promover a estabilidade dinâmica do joelho neutralizando o avanço cranial da tibial (*cranial tibial thrust*). Esta técnica envolve uma osteotomia radial na tíbia proximal com subsequente rotação do segmento proximal de modo a permitir uma precisa manipulação e redução do ângulo do plateau tibial. A cirurgia TPLO está associada a uma elevada taxa de sucesso, a curto e longo prazo, tanto em cães pequenos como grandes, apesar disso complicações intra cirúrgicas e pós-cirúrgicas poderão ocorrer após esta cirurgia. Neste estudo retrospectivo, as complicações a curto prazo após a cirurgia TPLO foram avaliadas e os factores de risco que podem influenciar a sua ocorrência foram analisados. De 38 cirurgias TPLO, a taxa geral de complicações foi de 56,2%, onde 15,8% foram complicações maiores e 36,8% complicações menores. Complicações menores observadas foram atraso na cicatrização, tendinite patelar, fractura da tuberosidade tibial, fractura de osteófito patelar com tendinite patelar e fractura fíbular iatrogénica. As principais complicações maiores incluíram três infecções e uma síndrome compartimental/infecção, uma falha do implante/fractura e um seroma com atraso de cicatrização. A complicação mais importante encontrada foi infecção e atraso na cicatrização e tendinite patelar foram as complicações menores mais frequentes. O único factor de risco encontrado foi o tamanho de implante, que talvez esteja relacionado com o peso corporal do paciente.

Em resumo, embora a cirurgia TPLO esteja associada a bons e excelentes resultados, geralmente metade dos casos pode desenvolver complicações, mais frequentemente, complicações menores e especialmente nas primeiras 4 semanas após a cirurgia.

Palavras-chaves: Ligamento cruzado cranial, tibial plateau levelling osteotomy, complicações a curto prazo, cão, cirurgia

ABSTRACT

SHORT-TERM COMPLICATIONS FOLLOWING A TPLO SURGERY:
RETROSPECTIVE STUDY OF 38 CASES

Cranial cruciate ligament (CrCL) rupture is one of the most common causes of pelvic limb lameness in dogs and its etiopathogenesis is not yet completely established. Trauma can be a reason for the acute ligament injury, although the majority of cases may be the result of chronic degenerative change. Surgical treatment appears to be the preferable treatment, to minimize joint instability and progression of degenerative joint disease. Even though, intra- and extra-capsular techniques have good outcomes, tibial osteotomies are generally preferred. The tibial plateau levelling osteotomy (TPLO) aims to provide dynamic stability of the stifle joint during weight-bearing by neutralizing the cranial tibial thrust. This technique involves a radial osteotomy of the proximal tibia with subsequent rotation of the proximal segment to enable precise manipulation and reduction of the tibial plateau angle (TPA). TPLO surgery is associated with high short and long-term success rates in both small and large dogs, nevertheless intraoperative and postoperative complications can occur.

In this retrospective study, the short-term complications after TPLO surgery were evaluated and risk factors that may influence its occurrence were analysed. Out of 38 TPLO surgeries, the overall complication rate was 56.2%, where 15.8% were major complications and 36.8% minor complications. Minor complications included delayed wound healing, patellar tendonitis, tibial tuberosity fracture, patellar osteophyte fracture with patellar tendonitis and iatrogenic fibular fracture. Major complications included three infections and one each of compartment syndrome/infection, implant failure/fracture and seroma with delayed wound healing. The more important major complication found was infection and delayed wound healing and patellar tendonitis were the more frequent minor complications. The only risk factor found was the size of implant which may be related to the patient’s body weight.

In summary, although TPLO is associated with good to excellent outcomes, generally half of the cases may develop complications, more often minor and especially in the first 4 weeks after surgery.

Key words: Cranial cruciate ligament, tibial plateau levelling osteotomy, short-term complications, dog, surgery.

TABLE OF CONTENTS

LIST OF FIGURES ... viii
LIST OF TABLES ... ix
LIST OF ABBREVIATIONS ... x
DESCRIPTION OF TRAINEESHIP ACTIVITIES ... xi
I. BIBLIOGRAPHIC REVIEW ... 1
1. ANATOMY AND BIOMECHANICS OF THE KNEE ... 1
1.1 Stifle joint anatomy ... 1
1.2 Biomechanics of the normal stifle ... 3
1.2.1 The Cranial Cruciate Ligament ... 4
2. CRANIAL CRUCIATE LIGAMENT RUPTURE (CRUCIATE DISEASE) ... 5
2.1 Pathogenesis ... 5
2.2 Epidemiology ... 6
2.3 Meniscal tears ... 8
3. DIAGNOSIS OF CRANIAL CRUCIATE LIGAMENT RUPTURE ... 8
3.1 Clinical history ... 8
3.2 Clinical signs ... 9
3.3 Diagnostic imaging ... 11
4. TREATMENT OF CRANIAL CRUCIATE LIGAMENT RUPTURE ... 13
4.1 Medical/Conservative managing ... 13
4.2 Surgical management ... 14
4.2.1 Extracapsular techniques ... 14
4.2.2 Intracapsular techniques ... 15
4.2.3 Tibial osteotomies ... 16
4.2.3.4 Tibial plateau levelling osteotomy ... 17
5. COMPLICATIONS ASSOCIATED WITH TIBIAL PLATEAU LEVELLING OSTEOTOMY ... 19
5.1 Degenerative joint disease ... 20
5.2 Infection ... 21
5.3 Delayed bone healing ... 23
5.4 Subsequent meniscal tear ... 24
5.5 Osteosarcoma ... 25
5.6 Patellar tendon thickening and tendonitis ... 26
5.7 Implant failure ... 26
5.8 Bone fractures ... 27
II. MATERIALS AND METHODS ... 29
1. Objectives and inclusion criteria ... 29

2. Signalment ...29
3. Radiographic assessment ...29
4. Procedures ...30
4.1 Measurement of the TPA, D1 and D2 and magnitude of rotation ...30
4.2 Preoperative management ...31
4.3 Surgical Technique ...32
4.4 Postoperative management ...34
4.5 Complications ...35
4.6 Statistic analysis ...35
III. RESULTS ...36
1. Signalment ...36
2. Radiographic and Surgical findings ...36
3. Radiographic re-evaluation and follow-up ...37
4. Complications ...37
4.1 Minor complications ...38
4.2 Major complications ...40
4.3 Risk factors analysis ...42
IV. DISCUSSION ...43
V. CONCLUSION ...51
REFERENCES ...52

LIST OF FIGURES

Figure 1. Ligaments and menici of the stifle joint (Left). (A) caudal view. (B) cranial view. (C) Lateral view. (D) Medial view. Adaptation from Evans and de Lahunda 2013 ... 2
Figure 2. Dorsal view of the menisci and ligaments of the left joint, proximal end of the tibia. From Kowaleski et al. 2012 ... 3
Figure 3. The cranial cruciate ligament prevents the cranial translation of the tibia. Adaptation from Schulz et al. 2019 ... 4
Figure 4. Demonstration of the cranial drawer test (A) and the cranial tibial trust test (B). Adaptation from Schulz et al. 2019 ...10
Figure 5. Illustration of a stifle with a Lateral fabellotibial suture technique (A) TightRope technique (B) and a bone model of Ruby Joint Stabilization (C) Adaptation from Tinga and Kim 2008 ...15
Figure 6. Illustration of the Cranial Tibial Closing Wedge Osteotomy (CTWO), Tibial Tuberosity Advancement (TTA) and Triple Tibial Osteotomy (TTO) procedures. Adaptation from Tinga and Kim 2008 ...16

Figure 7. Illustration of the theory proposed by Slocum in 1993 and the Tibial Plateau Levelling Osteotomy. Adaptation from Tinga and Kim 2008 18
Figure 8. Mediolateral and craniocaudal view radiographs of the right stifle of one dog that underwent TPLO at CHV-Frégis: immediately after surgery (A) and 8 weeks postoperatively (B), with evidence of bone healing. Provided by CHV-Frégis..30
Figure 9. Measurement TPA and D1 and D2. Provided by CHV-Frégis and adaptation from Kowaleski et al. 2012 30
Figure 10. First steps of the **s**urgical procedure: Incision on the medial proximal tibia (A); Arthrotomy and examination of the structures in the stifle joint (B); the joint surface identified by probing with a 25-gauge needle (C); the location of distances D1 and D2 marked on the tibial surface with un electrocautery (D e E). Provided by CHV-Frégis................................32
Figure 11. Some steps of TPLO surgery: Osteotomy (A and B); Placement of a pin to use as a rotation pin (C). Provided by CHV-Frégis...33
Figure 12. Some steps of TPLO surgery: Rotation and alignment of the tibial plateau segment and placement of a Kirschner wire (A and B); Placement and fixation of the TPLO implant (C); Closure of surgical site (D). Provided by CHV-Frégis. 33
Figure 13. Iatrogenic proximal fibular fracture, radiographic re-evaluation 4 weeks after surgery. Provided by CHV-Frégis. 38
Figure 14. Tibial tuberosity fracture at 4 weeks re-evaluation (A) and 8 weeks (B); Patellar osteophyte fracture at 4 weeks follow-up (C) and 8 weeks (D). Provided by CHV-Frégis. 39
Figure 15. Implant failure at 4 weeks after surgery (A) and stabilization (B). Provided by CHV-Frégis. 41

LIST OF TABLES

Table 1. Quick reference chart for TPLO rotation from DePuy Synthes Vet – www.synthesvet.com..31
Table 2. Degree of lameness 4 and 8 weeks after surgery: 0 (None) No lameness is observed at a walk or trot; 1 (Mild) Lameness is present, but may only be consistently apparent at a trot; 2 (Mild to moderate) Mild lameness is obviously present at a walk and is worse at a trot; 3 (Moderate) Obvious lameness is present at both gaits; 4 (Moderate to severe) Obvious lameness is present at both gaits and may be intermittently non-weightbearing; 5 (Severe) Lameness is non-weightbearing most or all of the time. 37
Table 3. Minor complications (defined as no further surgical intervention) following Tibial Plateau Levelling Ostectomy in 38 stifle joints. 39

Table 4. Major complications following Tibial Plateau Levelling Ostectomy in 38 stifle joints. 41

LIST OF ABBREVIATIONS

BOG - Bacterial overgrowth
CaCL - Caudal cruciate ligament
CHV-Frégis - Centre Hospitalier Vétérinaire Frégis
CrCL - Cranial cruciate ligament
CS - Compartment syndrome
CTA - Computed tomography arthrography
CTWO - Cranial tibial wedge osteotomy
CVWO - Chevron wedge osteotomy
DJD - Degenerative joint disease
ECVS - European College of Veterinary Surgeons
GI - Gastrointestinal
MOG - Malassezia overgrowth
MRI - Magnetic resonance imaging
MRSA - Methicillin resistant Staphylococcus aureus
MRSP - Methicillin resistant Staphylococcus pseudintermedius
NSAID - Non-steroid anti-inflammatory drug
OA - Osteoarthritis
PTIO - Proximal tibial osteotomy
SSI - Surgical site infection
TPA - Tibial plateau angles
TPLO - Tibial plateau levelling osteotomy
TR - TightRope
TTA - Tibial tuberosity advancement
TTO - Triple tibial osteotomy

DESCRIPTION OF TRAINEESHIP ACTIVITIES

The author's traineeship took place at Centre Hospitalier Vétérinaire Frégis (CHV-Frégis) located in Arcueil-France and it was performed under the Erasmus mobility program, with a total duration of four months starting on the $1st$ of November 2018 and ending on the $28th$ of February 2019, totalizing approximately 744 hours. The first two months were spent in the service of Internal Medicine and the last two at the service of Surgery.

The daily routine started at 7.30am, where a general examination of each hospitalized patient was performed by the author and the intern appointed to the service. The medical rounds started at around 8.00am in the presence of the day and night shift intern, surgery/ internal medicine clinicians, residents, board-certified specialists, a nurse and the trainee. A detailed presentation of each animal was made by the clinician responsible for the case or by the night shift intern. The attending specialist then proceeded to demand the elaboration of a differential diagnosis list and all the group participated in the discussion of the complementary exams, surgeries and treatments necessary.

In the Internal Medicine service, after the rounds, the trainee and the intern carried out the complementary exams previously discussed with the medical team. Some examples of the activities undertaken were collection of blood samples, measurement of blood pressure, packed cell volume, biochemical and urinary rapid parameters, insertion of vascular and urinary catheters, nasoesophageal feeding tubes and collection of urine through cystocentesis. Furthermore, the author helped with the positioning of patients for ultrasonographical examination, both abdominal and cardiac, management of fluid therapy, drug administration and blood transfusions.

In the Surgery service, once the rounds was over, both the trainee and the intern helped the on duty nurse with the application of bandages, management of fluid therapy and administration of treatments. Complementary exams were also performed as part of the activities. At the surgical theatre, the author helped prepare the patients for surgery, assisting with preparation and administration of anaesthesia and pre-medication, intubation, asepsis of the surgical field and transfer onto the surgical table. The author was also able to participate as assistant surgeon in some soft tissue and orthopaedic surgeries, and had the opportunity to observe several different surgeries such as laparoscopic ovariectomies, caesarean sections (and respective neonatal reanimation), correction of brachycephalic syndromes with a CO_2 laser, removal of intestinal foreign bodies, correction of patent ductus arteriosus, hemilaminectomy surgery, Tibial Plateau Levelling Osteotomies amongst others.

I. BIBLIOGRAPHIC REVIEW
1. ANATOMY AND BIOMECHANICS OF THE KNEE

1.1 Stifle joint anatomy

The stifle joint is a complex condylar synovial joint, composed of the femorotibial, femoropatellar and proximal tibiofibular joints (Dyce et al. 2010; Kowaleski et al. 2012; Evans and de Lahunta 2013). Different bones compose this joint: femur, proximal tibia and proximal fibula, and four sesamoid bones - the patella, lateral, medial and popliteal sesamoid (Kowaleski et al. 2012; Evans and de Lahunta 2013).

The main articulation is the femorotibial joint and it is formed between the condyles of the femur and the proximal end of the tibia, being the primary weight-bearing articulation (Kowaleski et al. 2012). To compensate for the incongruence between the articular surfaces, two fibrocartilaginous menisci are interposed between the femoral and tibial condyles (Dyce et al. 2010; Kowaleski et al. 2012; Evans and de Lahunta 2013).

The femoropatellar joint is formed by the articular surface of the patella and the femur. It communicates freely with the femorotibial joint, with which it is interdependent, as the patella is connected to the tibia by the patellar ligament (Kowaleski et al. 2012; Evans and de Lahunta 2013). This joint improves the efficiency of the extensor mechanism by assisting the function of the quadriceps muscle (Kowaleski et al. 2012). The joint capsule, the largest in the body, forms 3 freely intercommunicating sacs. Two, medial and lateral, at the femorotibial articulation and the third beneath the patella. The femorotibial sacs are divided by the menisci into femoromeniscal and tibiomeniscal parts. Distal to the patella, the fibrous layers of the joint capsule contain a large quantity of fat, the infrapatellar fat body.

As a diarthrose, the proper alignment of the bones is maintained by ligaments and a capsule of dense connective tissue, enclosing a sealed joint capsule containing the synovial fluid, a clear viscous liquid. The synovial fluid is produced by the synovial membrane that lines the joint cavity. It provides lubrication, nutrients and removes waste from the hyaline articular cartilage and it is primarily composed of water and a strongly polymerised hyaluronic acid (Mescher and Junqueira 2016).

The menisci are a semilunar fibrocartilaginous disk located between the condyles of the femur and the tibia. They have a thick and convex peripheral border, and the axial border is a thin concave free edge (König et al. 2020)The proximal surface is concave facing the femur condyles, whereas the distal surface is flattened in contact with the tibia condyles. They provide a nearly frictionless surface that gives lubrification and stability to the joint, compensating the incongruity between the articular surfaces, and also reducing the impact of the compressive forces, providing load bearing, load distribution and shock absorption (Kowaleski et al. 2012). The blood supply to the menisci is guaranteed by a perimeniscal capillary plexus, which originates from the medial and lateral genicular arteries and only penetrate in 15-25% of the menisci, the rest of the meniscus being mostly avascular (Kowaleski et al. 2012).

Ligaments are bands of dense regular connective tissue, consisting mostly of type I

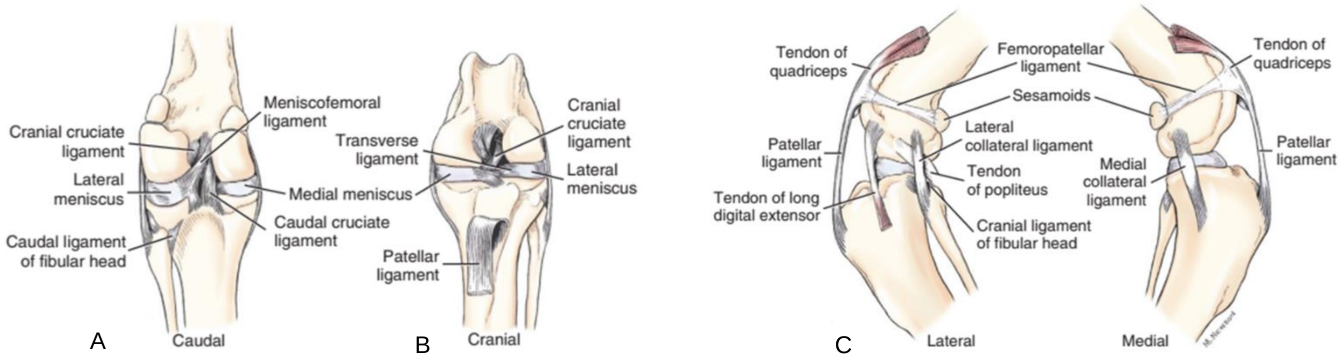


Figure 1. Ligaments and menici of the stifle joint (A) caudal view, (B) cranial view, (C) lateral and medial view. Adaptation from Evans and de Lahunda 2013

collagen fibers and fibroblasts aligned in parallel, that hold together components of the skeletal system (Mescher and Junqueira 2016). The ligaments of the stifle joint can be divided into the femoraltibial ligaments and the meniscal ligaments (figure 1). Four femorotibial ligaments provide primary ligamentous support: two collateral ligaments and two cruciate ligaments. Each meniscus is attached to the tibia by cranial and caudal ligaments and, in addition the lateral meniscus also has a ligament to the distal femur (Evans and de Lahunta 2013).

The cranial tibial ligament of the menisci extends from the cranial part of each meniscus to the lateral and medial intercondyloid area of the tibia, whereas the caudal tibial ligaments extend from the caudal angle of the lateral meniscus to the popliteal notch of the tibia and from the caudal angle of the medial meniscus to the caudal intercondyloid area of the tibia. The femoral ligament of the lateral meniscus connects the caudal angle of the lateral meniscus to the inside of the medial femoral condyle. There is a transversal ligament that connects both menisci by the cranial angle. The medial meniscus is more firmly attached to the tibia then the lateral meniscus, since its periphery is attached to the joint capsule and the abaxial border blends into the medial collateral ligament, providing a strong connection to the tibia (Evans and de Lahunta 2013).

The lateral collateral ligament arises from the lateral condyle of the femur and ends with a strong branch on the head of the fibula and a few fibres attaching in the adjacent lateral condyle of the tibia. The medial collateral ligament extends between the medial condyle of the femur to attach on the medial tibial condyle and during its course blends with the joint capsule and has a strong attachment to the medial meniscus (Evans and de Lahunta 2013).

The cruciate ligaments are considered extrasynovial because they are covered by synovium even though they are intra-articular. They are designated cranial and caudal based on their tibial attachment and they cross each other, hence their name (figure 2). The cranial cruciate ligament (CrCL) crosses diagonally from the caudalmedial part of the lateral condyle of the femur to the cranial intercondyloid area of the tibia, whereas the caudal cruciate ligament (CaCL) runs from the lateral surface of the medial femoral condyle to the lateral edge of the popliteal notch of the tibia (Evans and de Lahunta 2013).

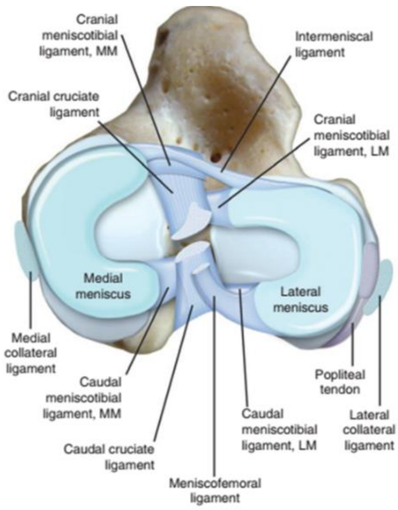


Figure 2. Dorsal view of the menisci and ligaments of the left joint, proximal end of the tibia. From Kowaleski et al. 2012

1.2 Biomechanics of the normal stifle

Flexion and extension are the primary types of motion of the stifle with the normal range being approximately 140 degrees, and rotation is the secondary type of motion. The Labrador Retriever's goniometry of median flexion and extension angles were measured at 41 degrees and 162 degrees, respectively, with a range of motion of 121 degrees (Kowaleski et al. 2012).

In a study by Kim at al., the cinematic of the femorotibial joint was characterized by fluoroscopy during daily activities such as walk, trot, sitting and stair ascending, with the mean flexion and extension being measured at 150 and 35 degrees, respectively. A positive correlation was also found between the internal rotation of the tibia and the flexion of the knee during the different daily activities of the dog (Kim et al. 2015).

Excessive joint motion and stabilization of the knee are regulated by a complex system of reflex arcs that involves the primary muscles groups of the stifle (Solomonow et al. 1987) and a series of mechanoreceptors and proprioreceptors (Yahia et al. 1992; Arcand et al. 2000) located in the ligaments, joint capsule, and associated muscles (Solomonow et al. 1987).

In extension, the collateral ligaments are the primary stabilizers limiting internal and external rotation and both ligaments are taut. In flexion, the lateral collateral ligament is looser while most of the medial collateral ligament remains taut, with the exception of the caudal border which shows some loosening, resulting in an internal rotation of the tibia and, as the joint extends, the tightness of the ligaments results in an external rotation of the tibia (Vasseur and Arnoczky 1981).

The stifle joint is capable of slight varus and valgus angulation. In full extension the medial collateral ligament limits de valgus angulation and the lateral collateral ligament in combination with the cranial cruciate ligament limit the varus angulation. In 90 degree flexion, the 4 femorotibial ligaments limit valgus angulation, whereas the varus angulation is limited by the lateral collateral ligament and both cruciate ligaments (Kowaleski et al. 2012). The cruciate ligaments have a major role in maintaining the stabilization of the stifle joint (Solomonow et al. 1987).

The primary restraint against caudal tibial translation in relation with the femur is the caudal cruciate ligament. This ligament also limits the internal rotation of the tibia by twisting with the cranial cruciate ligament and it is the secondary restraint against hyperextention. It contains a larger cranial band that is lax in extension and taut in flexion and a second and smaller caudal part that is lax in flexion and taut in extension (Kowaleski et al. 2012).

1.2.1 The Cranial Cruciate Ligament

The CrCL is the primary restraint against cranial tibial translation with respect to the femur (cranial drawer) and hyperextension (figure3). It can be grossly divided into 2 bands: a

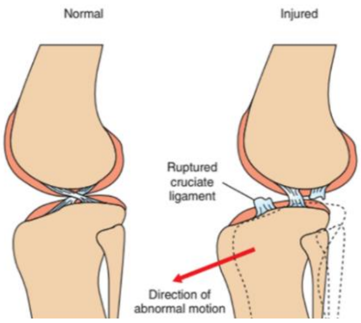


Figure 3. The cranial cruciate ligament prevents the cranial translation of the tibia. Adaptation from Schulz et al. 2019

larger caudalateral part that attaches at the caudalateral aspect of the tibial attachment site and a smaller craniomedial band that attaches to the craniomedial part of the tibial attachment site.

As previously described, this ligament crosses diagonally from the caudalmedial part of the lateral condyle of the femur to the cranial intercondyloid area of the tibia, during its course the craniomedial fibers spiral approximately 90 degrees (Kowaleski et al. 2012). This twist results in the appearance of two distinct and functionally discrete bands, especially in flexion. The craniomedial band is taut in both flexion and extension and the caudalateral band is taut in extension and lax in flexion, therefore the craniomedial band is the primary check against cranial tibial subluxation. In short, the biomechanical functions of the CrCL are preventing the cranial drawing of the tibia, the overextension of the knee and the internal rotation of the tibia in relation to the femur (Kowaleski et al. 2012).

2. CRANIAL CRUCIATE LIGAMENT RUPTURE (CRUCIATE DISEASE)

2.1 Pathogenesis

CrCL rupture is one of the most prevalent causes of orthopaedic degenerative disease in the dog (Hayashi et al. 2003) and its etiopathogenesis is not yet completely established (Hayashi 2017).

Trauma is known to be a reason for acute ligament injury resulting in the rupture of the CrCL, although several studies have suggested that the majority of the cases are a result of chronic degenerative changes in the ligament (Vasseur 1984; Hayashi et al. 2003). These changes involve a gradual degeneration of the ligament, inflammatory disease in the stifle joint, partial CrCL rupture and eventually complete rupture. Lameness may not occur initially, but these changes can produce mild instability within the join and therefore initiate the process of osteoarthritis degeneration (Hayashi 2017).

Histologically, the degenerative changes include decreased cell density of ligament fibroblasts, chondroid metaplasia of surviving ligament fibroblasts and extensive disruption to the organized hierarchical architecture (Hayashi et al. 2003). Some degree of tissue repair has been described after partial or complete rupture of the ligament (Hayashi et al. 2003), although a bridging scar does not form in the rupture site and the ruptured ends of the CrCL are eventually covered by synovial tissue (Hayashi 2017).

Other factors that may be involved in the process of CrCL rupture are inflammatory arthropathies in the presence of immuno-mediated of infective inflammatory arthropathies that can lead to development of changes within the ligament leading to its rupture (Galloway and Lester 1995; Denny and Butterworth 2000; Doom et al. 2008).

CrCL rupture has been determined to be a multifactorial complex disease with multiple genetic and environmental risk factors. There is not a single combination of risk factors that determine invariably that the dog will develop a CrCL rupture. Although, understanding these risk factors can help to identify dogs that are more susceptible to the condition and guide patient management (Hayashi 2017).

1

2.2 Epidemiology

CrCL injury has been considered one of the most common causes of pelvic limb lameness in dogs (Witsberger et al. 2008), although different studies have estimated the prevalence to range from 0,6 to 2.6% (Witsberger et al. 2008; Taylor-Brown et al. 2015).

As a chronic degenerative disease, it occurs primarily in middle-age dogs (Whitehair et al. 1993; Reif and Probst 2003; Witsberger et al. 2008). Whitehair et al. (1993) reported a peak prevalence in dogs aged 7 to 10 years old, and Witsberger et al. (2008) identify "Age" as a risk factor with dogs > 4years old significantly more likely to have CrCL rupture. A more recent study shows that dogs aged over 3 years old have increased odds of diagnosis compared with younger dogs (Taylor-Brown et al. 2015).

Furthermore, dogs with bilateral CrCL injury were proven to be significantly younger than dogs with unilateral CrCL rupture (Cabrera et al. 2008; Grierson et al. 2011).

Breed has been identified as a risk factor (Witsberger et al. 2008; Taylor-Brown et al. 2015) and certain breeds such as Rottweiler, Newfoundland, Staffordshire Terrier, Neapolitan Mastiff, Akita, Saint Bernard, Labrador Retriever, Golden Retriever, West Highland White Terrier, Bulldogs, Boxer, Chow Chow and Yorkshire Terrier have been reported to have increased odds or a predisposition to develop degenerative disease of the CrCL (Whitehair et al. 1993; Duval et al. 1999; Witsberger et al. 2008; Taylor-Brown et al. 2015). On the contrary, Miniature Dachshund, Dachshund, Greyhound, Shih Tzu, Miniature Schnauzer and Pekingnese breeds were identified to have significantly lower probability of being diagnosed with CrCL disease (Witsberger et al. 2008).

Many recent studies have been conducted to characterize the genetic basis of this disease (Wilke et al. 2009; Baird et al. 2014a; Baker et al. 2017). Heritability is considered moderate and was estimated for three breeds, Boxer, Newfoundland and Labrador Retriever, at ranging from 0.27 to 0.48 (Nielen et al. 2003; Wilke et al. 2006; Baker et al. 2017). It was suggested in these studies, that CrCL rupture is a highly polygenic complex trait disease where biological networks that control collagen genes (Baird et al. 2014a), neurological pathways (Baird et al. 2014b), innate immune mechanisms (Baker et al. 2017) and aggrecan signalling (Wilke et al. 2009; Baker et al. 2017) may all play a role in the CrCL rupture's pathogenesis. Therefore, Baird et al. (2014a) concluded that strength and stability of the CrCL may be compromised by mutations leading to an increased risk of CrCL rupture and Baker et al. (2017)

considered that genetic risk is influenced by multiple genomic loci with small individual additive effects. Ultimately, these genetics research could be used to identify at risk individuals before rupture occurs and control environmental variables that are known to contribute to CrCL rupture and provide opportunity for medical intervention (Baker et al. 2017).

Neutered dogs, females and males, have been reported to have significantly higher prevalence and increased risk of CrCL rupture compared with intact dogs (Whitehair et al. 1993; Duval et al. 1999; Witsberger et al. 2008; Taylor-Brown et al. 2015). Grierson et al. (2011), however, found evidence that all male dogs, intact and neutered, had higher probability of developing bilateral CrCL rupture than females, intact or neutered. Another study suggested that early neutering (<1year) significantly increases the odds of developing CrCL rupture at least in Golden Retrievers (Torres de la Riva et al. 2013).

Body weight has also been associated with higher prevalence of this disease (Whitehair et al. 1993; Duval et al. 1999; Taylor-Brown et al. 2015), with dogs over 22 kg having an increased risk compared to dogs under 22 kg (Whitehair et al. 1993). Weight gain is pointed often as an explanation for increased prevalence of orthopaedic diseases in neutered dogs (Whitehair et al. 1993; Duval et al. 1999), although Torres de la Riva et al. (2013) observed that the effects of early neutering persisted after adjusting for differences in body condition score and suggested that absence of sexual hormones can leads to atypical growth plate closure and, therefore, altered conformation (Torres de la Riva et al. 2013). In fact, early neutering has been reported as a risk factor for developing excessive Tibial Plateau Angles (TPA) in large dog breeds (Duerr et al. 2007).

Another factor that can predispose to CrCL degeneration is the anatomy of the stifle joint, with several studies having evaluated different anatomic factors such as narrow intercondular notch (Lewis et al. 2008), excessive or pathologic tibial plateau angle (Reif and Probst 2003; Duerr et al. 2007; Cabrera et al. 2008; Inauen et al. 2009; Ragetly et al. 2011) overall limb alignment (Mostafa et al. 2009) and proximal tibial conformation (Reif and Probst 2003; Cabrera et al. 2008; Ragetly et al. 2011; Fuller et al. 2014; Haynes et al. 2015).

Although, some studies have shown an influence of TPA in the strain of the CrCL and that an increased TPA can contribute to pathogenesis of CrCL disease (Morris and Lipowitz 2001; Duerr et al. 2007; Mostafa et al. 2009; Haynes et al. 2015), other studies cannot find a significant relationship between TPA and uni or bilateral CrCL rupture (Wilke et al. 2002; Reif and Probst 2003; Cabrera et al. 2008; Fuller et al. 2014). So, no study has definitively shown TPA to be a significant risk factors for CrCL injury in dogs (Baker and Muir 2017).

Although, a study found that a multivariate approach of conformation characteristics of the stifle joint (TPA and femoral anteversion angle) on a regression model was superior in identifying risk factors for CrCL disease in Labrador Retrievers (Ragetly et al. 2011). No definitive evidence that the conformation of the stifle joint is a primary causal factor for CrCL rupture has been reported (Baker and Muir 2017).

Possibly, the greatest risk factor for developing a CrCL rupture is having been already diagnosed previously, with the incidence of contralateral rupture after 1st diagnosis ranging from 22% to 54% (Moore and Read 1995; de Bruin et al. 2007; Cabrera et al. 2008; Buote et al. 2009; Grierson et al. 2011; Fuller et al. 2014; Baker and Muir 2017) and the incidence of bilateral rupture at initial clinical presentation ranging from 11% to 22% (de Bruin et al. 2007; Cabrera et al. 2008; Buote et al. 2009; Fuller et al. 2014). Also, the presence of radiographic synovial effusion and osteophytosis in the stable contralateral stifle at the time of diagnosis can identify dogs at greater risk for bilateral rupture (Fuller et al. 2014; Baker and Muir 2017).

2.3 Meniscal tears

Meniscal injury is commonly associated with CrCL disease (Bennett and May 1991; Ralphs and Whitney 2002; Fitzpatrick and Solano 2010), with the incidence ranging from 33.2% to 77% (Ralphs and Whitney 2002; Fitzpatrick and Solano 2010) and it affects more often the medial meniscus (Ralphs and Whitney 2002; Lampman et al. 2003; Fitzpatrick and Solano 2010). Damage in the lateral meniscus in an arthroscopy study was reported at an incidence of 77%, although its clinical significance remains unknown (Ralphs and Whitney 2002).

Meniscal tears amenable to repair are rare, with most of those found in dogs with CrCL rupture involving the avascular portion of the meniscus, so conservative treatment is not recommended (Thieman et al. 2009). Meniscal damage of the caudal horn has been classified based on its appearance: radial, vertical longitudinal, “bucket handle”, flap and complex tears (Thieman et al. 2009), with bucket handle tear being the most common lesion of the medial meniscus reported (Case et al. 2008; Ritzo et al. 2014). The recommended treatment for these lesions is resection of the damaged area by partial, hemi or total meniscectomy, without damaging surrounding articular cartilage.

1

3. DIAGNOSIS OF CRANIAL CRUCIATE LIGAMENT RUPTURE

3.1 Clinical history

Owners will often suggest a history of trauma. After careful analysis, it is common to reveal either insidious onset lameness or minor trauma in daily activity (Muir 2017). A clear history of major trauma is also possible but rare and often associated with an avulsion fracture of the cranial cruciate ligament attachment site (Muir 2017). The large majority will not have a history of trauma or contact injury, instead, since CrCL disease is a degenerative and progressive condition, the lameness may be subtle and only noticed after strong activity, if stable partial tears have occurred (Kowaleski et al. 2012; Muir 2017). In a complete rupture, lameness will be non-weight bearing or at least severe (Kowaleski et al. 2012).

Patients are also frequently presented for treatment of a subtle lameness usually persistent and unresponsive to non-steroid anti-inflammatory therapy (NSAID). Attentive owners may notice a bilateral lameness and shift pelvic limb gait with weight shifting to the thoracic limbs and, also lameness may appear to shift from one limb to the other, when the rupture is bilateral. In those cases, patients developed arthritis, but the stifle is stable (Muir 2017). The duration of lameness can be very variable and an audible “click” can be reported by the owner during walking, which may be indicative of meniscal injury (Muir 2017).

3.2 Clinical signs

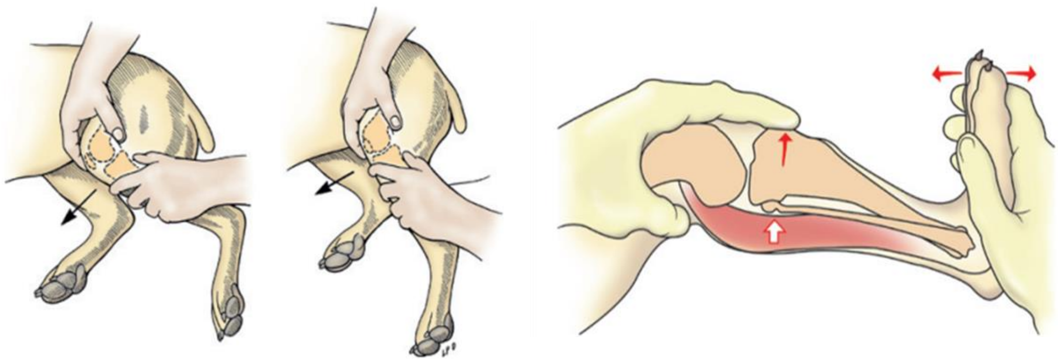
On physical examination, dogs usually exhibit a uni or bilateral weight-bearing lameness, occasionally can be evident a non-weight-bearing lameness, more commonly following an acute CrCL rupture (Muir 2017). May exist an external rotation of the limb evident when walking, also may be present in the sitting position. Quite often, dogs with CrCL rupture have an inability to sit straight and square, with the calcaneus not directly underneath the tuber ischia, due to the stifle not being completely flexed. During walk, occasionally an audible clicking can be heard that usually indicates meniscal damage, typically concurrent with CrCL rupture. On general examination, muscle atrophy can be evident in the affected limb, especially in chronic cases (Muir 2017).

On the stifle observation, effusion is typically found, with the margins of the patella tendon feeling indistinct to palpation. Sometimes, if effusion is too discrete and may not be detected by palpation, radiography may be a better diagnostic test to evaluate the presence of joint effusion (Muir 2017). The presence of medial buttress is almost always indicative of CrCL rupture and consists of a firm thickening on the medial side of the stifle detected by palpation, indicative of periarticular fibrosis. During flexion and extension of the stifle, crepitation and increased or decreased range of motion during manipulation may be found, depending on the chronicity of the injury (Muir 2017).

Cranio-caudal instability between the tibia and femur can be identified with two specific tests (figure 4), the cranial drawer test and the cranial tibial thrust (Henderson and Milton 1978; Muir 1997). These two tests are performed with the patient in lateral recumbency with the affected limb on an upward position and the stifle in partial flexion at a normal standing angle

(Muir 2017). The cranial drawer test required the thumb of one hand to be placed behind the lateral fabella and the index to be placed on the patella, the thumb of the other hand should be placed behind the fibular head and the index should be on the tibial tuberosity (Kowaleski et al. 2012). The tibia is firmly manipulated in a caudal and cranial direction, in the sagittal plan, and the motion is monitored. A positive result is given by cranial translation of the tibia relative to the femur. In dogs with chronic stifle arthritis, the subtle instability may be missed during these tests, due to periarticular fibrosis that may reduce the cranial translation of the tibia relative to the femur. And in young puppies, a small and physiological degree of instability may be present (Kowaleski et al. 2012; Muir 2017).

The cranial tibial thrust is performed with the index finger of one hand placed on the tibial tuberosity and the thumb, palm and remaining fingers are used to grasp the femoral condyles and to maintain stifle joint position. The other hand is used to grab the metatarsus and alternately flex and extended the hock joint, simulating the contractions of the gastrocnemius muscle and the tibial compression mechanism. An intact CrCL would counters the cranial tibial trust, however, if it is ruptured, cranial tibial translation occurs and will be noted by a cranial to caudal motion on the index finger (Kowaleski et al. 2012; Denny and Butterworth 2000).



A B

Figure 4. Demonstration of the cranial drawer test (A) and the cranial tibial trust test (B). Adaptation from Schulz et al. 2019

To ensure that subtle instabilities are not missed, these tests can be repeated under sedation or general anaesthesia, this may be important because the cranial drawer test can be painful and many dogs dislike it, especially nervous dogs with tense muscles and dogs with chronic stifle arthritis (Corr 2009; Muir 2017).

The detection of cranial drawer and cranial tibial trust remains a key part of the diagnostic of CrCL rupture, however the stifle instability can be difficult to distinguish, therefore these tests must be interpreted with caution and along with others clinical signs and observations from other diagnostic tests (Muir 2017).

3.3 Diagnostic imaging

3.3.1 Radiography

Radiographic changes are non-specific and mainly correspond to changes secondary to CrCL disease (Denny and Butterworth 2000). Nevertheless, radiographic examination is important in all cases to verify osteoarthritis in routine cases, to confirm diagnostic in cases of partial CrCL rupture and to exclude other disorders such as fracture or neoplasia (Kowaleski et al. 2012). Both stifles should be radiographed for comparison and mediolateral and craniocaudal projections of the stifle are taken. Synovial effusion, one of the earliest and most consistent findings (Kowaleski et al. 2012), is identified by partial or complete replacement of the infrapatellar fat opacity by soft tissue opacity and by distension of the joint capsule, mostly observed caudally (Kowaleski et al. 2012; Denny and Butterworth 2000).

Osteophyte and/or enthesiophyte formation are also a very consistent and early finding, particularly in partial tear of CrCL and likely to appear in the region of the ligament attachment within the cranial intercondyloid area of the tibia (Kowaleski et al. 2012). Periarticular osteophytosis is commonly observed first around the proximal margins of the trochlea and poles of the patella and later around the fabella and edges of the tibial plateau. In more advanced cases of osteoarthritis, sclerosis of subchondral bone and soft tissue mineralization can be seen (Denny and Butterworth 2000).

To improve diagnostic accuracy, stress radiography can be used to quantify cranial tibial translation radiographically (Kim 2017). These radiographies are performed while doing a modified tibial compression test (de Rooster et al. 1998) or using special devices that attempt to force the stifle into drawer (Lopez et al. 2004) or standing radiographies where the intrinsic forces, that are present during standing, promote cranial tibial translation in the CrCL deficient stifle (Kim 2017). To detect the translation of the tibia relative to the femur, the alignment between both is compared on lateral views of the stifle after applying a cranial tibial translational load (Kim 2017).

The different methods use specific femoral and tibial landmarks and calculate the distance between them along a defined axis of translation, where the difference in the distance defines the amount of laxity (Kim 2017). These measurements are affected by the radiographic positioning and any minor obliquity of the projection will significantly affect the calculated distances, therefore the results. So, it is imperative in all of the methods to obtain perfect lateral projections. Another variable to considered is the flexion of the stifle, as the flexion angle must be consistent between stressed and non-stresses views. The majority of methods advocate using a flexion angle of 90º (Kim 2017).

De Rooster et al. (1998) determined that the tibial compression radiography, where the stressed views are obtained performing a tibial compression test, has 97% sensitivity and 100% specificity for detection of CrCL rupture.

In summary, stress imaging techniques are useful to confirm a diagnosis of CrCL rupture, particularly when the cranial drawer sign is not obvious on physical examination or when the clinicians have less experience and confidence in stifle palpation (Kim 2017).

3.3.2 Ultrasonography

Musculoskeletal ultrasound requires a high-resolution, linear transducer within a range of 8-15 MHz and to evaluate the stifle joint, 10-18 MHz are recommended in order to obtain highly detailed images of superficial structures while minimizing the artifacts from anisotropy, that occurs when the ligament's fibres are not perpendicular to the ultrasound beam (Kramer et al. 1999; Cook 2016; Cook 2017).

Different structures can be identified during the ultrasound such as the patellar ligament and tendon, collateral ligaments, cranial joint space, including the infrapatellar fat pad, synovium and cranial cruciate ligament, and both the medial and the lateral menisci (Kramer et al. 1999; Cook 2016). The caudal cruciate ligament can be very difficult to visualize due to the large muscle mass along the caudal joint (Kramer et al. 1999; Arnault et al. 2009; Cook 2016).

Although this exam has a high sensitivity and specificity for the diagnosis of meniscal injuries, 90.0% and 92.9%, respectively (Mahn et al. 2005), the diagnosis of CrCL rupture can be difficult, with some studies showing only 15.4% to 19.6% of the cases being correctly diagnosed (Gnudi and Bertoni 2001; Arnault et al. 2009).

In a normal stifle, the CrCL is seen as a hypoechoic structure compared to the patellar tendon, whereas in a chronic injury an irregular and thickened CrCL may be seen with retraction of the ends at the site of the tear (Cook 2017). In acute injuries, the CrCL may not be seen ultrasonographically (Kramer et al. 1999), the joint effusion can be mild to severe and potentially have echogenic fluid if there is a significant hemarthrosis (Cook 2017).

3.3.3 Computed tomography

Computed tomography arthrography (CTA) has proven to easily identify the ligamentous structures of the normal stifle joint (Samii and Dyce 2004) and has shown an accuracy in diagnosing complete or partial CrCL tears (Han et al. 2008; Samii et al. 2009) and medial meniscal injuries (Tivers et al. 2008; Tivers et al. 2009).

Samii et al. (2009) showed CTA to be very sensitive and specific in diagnosing CrCL rupture but less so for meniscal tears, considering this exam to have limited value, although Tivers et al. (2008), in his cadaver study, showed that dorsal CTA images had a sensitivity of 90% and a specificity of 100%.

3.3.4 Magnetic resonance imaging

MRI is considered accurate to diagnose CrCL rupture and meniscal tears in dogs (Galindo-Zamora et al. 2013). However, due to the high costs and anaesthesia time required for this procedure and the little evidence that it improves patient care, more cost-effective diagnostic methods are normally chosen, such as radiography, ultrasonography, or arthroscopy (Scrivani 2017).

3.3.5 Arthroscopy

Arthroscopy is the method of choice for joint exploration, providing an accurate examination and treatment of joint pathology (Whitney 2003). With minimally invasive means and complete visualization of the intra-articular structures, by magnification and a highly illuminated environment, viewing is greatly improved over traditional arthrotomy and allows improved diagnostic capability (Ralphs and Whitney 2002). It is particularly useful to detect partial tears of the CrCL and an early diagnosis is important so that treatment can be provided in the early stage of CrCL disease. Therefore, it may not only reduce the advance of osteoarthritis, but also allow for preservation of the integrity of the remaining ligament fibres, contributing to reduce the chances of developing a meniscal tear later(Whitney 2003).

Arthroscopic-assisted arthrotomy is minimally invasive, allows accurate treatment, reduces pain and swelling after surgery that helps to preserve joint range of motion and reduces surgical morbidity (Beale et al. 2017).

4. TREATMENT OF CRANIAL CRUCIATE LIGAMENT RUPTURE

4.1 Medical/Conservative managing

Surgical treatment appears to be the preferable option for CrCL rupture, to minimize joint instability and progression of degenerative joint disease (DJD), regardless of body weight and especially in younger and active patients (Vasseur 1984; Schulz et al. 2018). However, conservative treatment is normally the first choice for small dogs (<15kg) (Comerford et al. 2013), since clinical improvement is possible with non-surgical treatment alone (Vasseur 1984; Wucherer et al. 2013). Nevertheless, surgical treatment in association with conservative management has better overall outcomes compared with only non-surgical options (Wucherer et al. 2013). In some cases, conservative treatment is required to relieve clinical signs in dogs not suitable for surgical treatment either due to age, health condition or financial constraints.

Conservative management is a multimodal therapy that aims to minimize pain originated by osteoarthritis, maintain or improve limb use and slow the progression of DJD. This therapy typically consists of restriction of activity, weight loss, analgesic medication, chondroprotective agents, nutritional/dietary supplements and physical therapy (Jerram and Walker 2003; Budsberg 2017).

4.2 Surgical management

Surgical stabilization is recommended in patients of any size to ensure optimum function of the limb, to minimize joint instability and progression of DJD, and to allow for inspection of meniscus's integrity and treatment of lesions that may be present (Denny and Butterworth 2000; Schulz et al. 2018). The surgical technique chosen may depend on the surgeon's preference, patient size, function and level of activity, and treatment costs, since most studies report a success rate of near 90% regardless of the technique (Comerford et al. 2013; Duerr et al. 2014; Schulz et al. 2018). In general, surgical techniques are divided into intra-articular, extracapsular and tibial osteotomies. Intra-articular and extra-capsular surgical techniques focus on recreation of the passive constraints of the stifle joint while tibial osteotomies intend to achieve stabilization by changing the anatomy and therefore the stifle biomechanics (Schulz et al. 2018).

4.2.1 Extracapsular techniques

Extracapsular stabilizations include a series of different techniques designed to stabilize the joint by placing biological or synthetic sutures outside the joint to counteract the translational and rotational instability that is present when the CrCL is damaged (Kowaleski et al. 2012; Tinga and Kim 2017; Schulz et al. 2018). These techniques lean on periarticular fibrosis to provide function and stability of the stifle in the long-term because the stability first created by these techniques is relatively short lived (Kowaleski et al. 2012). The advantages of these procedures are low technical difficulty, minimal required inventory and relatively low costs, with good outcomes in terms of safety and efficiency, even when compared with the outcomes of tibial osteotomies (Conzemius et al. 2005; Au et al. 2010; Cook et al. 2010; Christopher et al. 2013; Tinga and Kim 2017). The disadvantages reported include abnormal biomechanics, higher infection rate, and poorer long-term stability (Tinga and Kim 2017).

The lateral fabellotibial, TightRope CCL® and the Ruby Joint Stabilization System are some of the extra-articular surgical techniques used in the CrCL (figure 5).

Complications associated with extracapsular techniques include suture reaction, peroneal nerve damage, incorrect implant placement, postoperative implant loosening, postoperative meniscal tear, and infection (Casale and McCarthy 2009), and some studies have reported complication rates from 11.8 % to 29.2% (Casale and McCarthy 2009; Cook et al. 2010; Muro and Lanz 2017). Body weight (more than 35kg) and young age of the patient (less than 5-year-old) were described as risk factors and associated significantly with higher complication rate (Casale and McCarthy 2009).

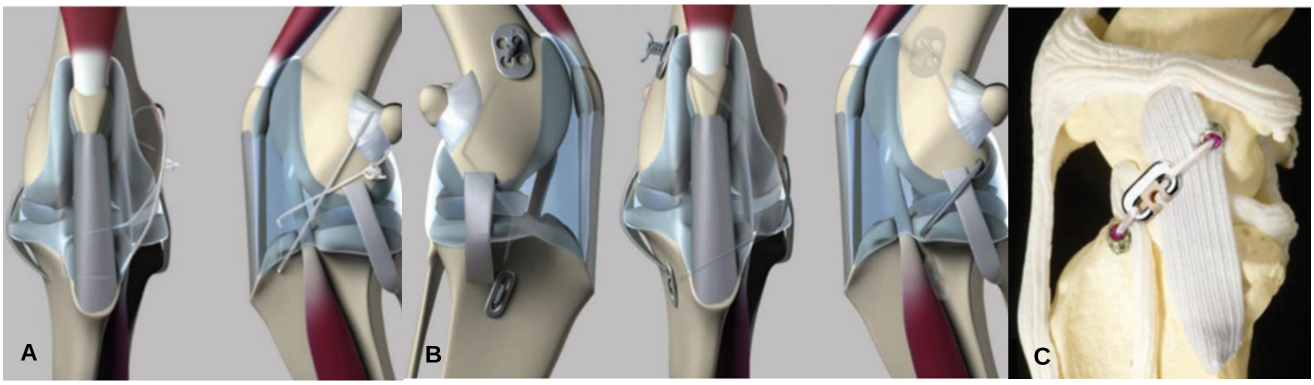


Figure 5. Illustration of a stifle with a Lateral fabellotibial suture technique (A) TightRope technique (B) and a bone model of Ruby Joint Stabilization (C). Adaptation from Tinga and Kim 2008

4.2.2 Intracapsular techniques

Intracapsular reconstruction consists of repairing or replacing the ligament with a graft, passing it through the joint using the "over-the-top" method or through predrilled holes in the femur or tibia, or both (Schulz et al. 2018).

The "over-the top" procedure and many other techniques have been described for replacing the CrCL using autografts, allografts or prosthetics (Biskup and Conzemius 2017).

In human medicine, the "gold standard" for anterior cruciate ligament rupture repair is intra articular replacement with a graft, where the ideal ligament substitute should mimic not only the ligament anatomy, but also its biomechanical properties (Kowaleski et al. 2012). In veterinary medicine major complications are associated with possible stretching, rupture, and infection of the ligament substitute (Schulz et al. 2018).

4.2.3 Tibial osteotomies

Even though, intra- and extra-capsular techniques have good outcomes with good limb function reported, these techniques are far from having optimal long-term outcomes, failing to consistently maintain stability and are also associated with continued progression of DJD (Jerram and Walker 2003; Kim et al. 2008).

Therefore, tibial osteotomy techniques were designed to eliminate the cranial tibial thrust producing dynamic or functional stability during weight bearing by altering the bone geometry (Jerram and Walker 2003; Corr 2009; Schulz et al. 2018). This new concept was born when Slocum, in 1984, described the cranial tibial wedge osteotomy (CTWO), which allows dynamic stabilization of the CrCL-deficient stifle, with no need for passive restraint against laxity (Corr 2009; Schulz et al. 2018). It is based on the theory that the tibial plateau angle (TPA) is a major factor in stifle biomechanics, influencing the magnitude of cranial shear force and that reducing the TPA will eliminate the cranial sub luxation of the tibia during weight-bearing (Kim et al. 2008; Pozzi et al. 2017). Several procedures (figure 6) relying on the same theory have since then been described, such as tibial plateau levelling osteotomy (TPLO), combined TPLO/CTWO, triple tibial osteotomy (TTO) and chevron wedge osteotomy (CVWO). The tibial tuberosity advancement (TTA), is another technique that attempts to achieve

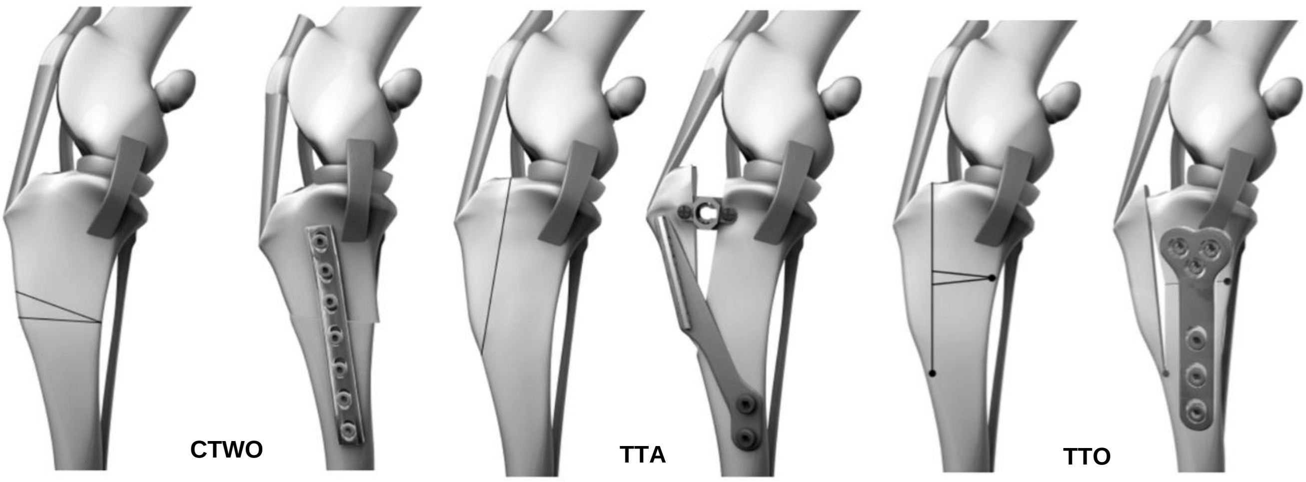


Figure 6. Illustration of the Cranial Tibial Closing Wedge Osteotomy (CTWO), Tibial Tuberosity Advancement (TTA) and Triple Tibial Osteotomy (TTO) procedures. Adaptation from Tinga and Kim 2008

dynamic stabilization by changing the relative alignment of the patellar tendon to the tibial plateau (Kim et al. 2008).

Several other procedures have been described, such as a combination between CTWO and TPLO and proximal tibial osteotomy (PTIO) with each procedure presenting unique methods developed to overcome certain limitations of the conventional tibial osteotomies described above (Kim et al. 2008).

4.2.3.4 Tibial plateau levelling osteotomy

The tibial plateau levelling osteotomy (TPLO) was first described by Slocum, in 1993, for treatment of CrCL rupture and aims to provide a dynamic stability of the stifle joint during weight-bearing by neutralizing the cranial tibial thrust (Slocum and Slocum 1993). The stifle is redesigned so that the CrCL is not necessary for the stabilization and that the cranial tibial thrust is controlled by levelling the tibial slope, which will enhance the effectiveness of the active forces of the stifle flexors of the thigh, the hamstrings and bicep femoris muscles (Slocum and Slocum 1993).

TPLO involves a radial osteotomy of the proximal tibia with subsequent rotation of the proximal segment to enable precise manipulation and reduction of the tibial plateau slope (figure 7). Because this technique does not attempt to restore the passive constrains of the CrCL, cranial tibial translation can still be present after surgery (Slocum and Slocum 1993).

The intent of TPLO surgery is to obtain a TPA of 5º, although in a cadaver study a biomechanical analysis demonstrated that a final TPA of 6.5º±0.9 degrees neutralize the cranial tibial subluxation and induces a caudal tibial subluxation (Warzee et al. 2001; Reif et al. 2002), while further rotation will increase strain in the CaCL resulting in an excessive CaCL stress (Warzee et al. 2001). In contrast, three-dimensional computer modelling of the canine stifle revealed that a final TPA of 5 degrees did not substantially decrease the load on the CrCL (Shahar and Milgram 2006), however this study is based on a mathematical model that may not completely mimic the clinical situation.

While these studies assume that TPLO provides dynamic stabilization by altering the TPA, several other studies prove that this procedure alters the PTA to 90º and suggest that the biomechanics principle and mechanisms of action of TPLO may be similar to TTA (Drygas et al. 2010; Sathya et al. 2014). This finding may help to explain the observation that dogs with TPA ≤ 14º after TPLO had clinically good outcomes (Duerr et al. 2008).

Preoperative and intraoperative planning of the surgery is important and allows a more centred osteotomy, reducing the risk of postoperative complications (Collins et al. 2014). There are a variety of methods to help position a TPLO and Collins et al. (2014) suggest that preoperative measurements made from radiographs can be used intraoperatively, to obtain a more reliable and accurate intraoperative osteotomy position. Different planning techniques were compared and proved that measuring the distance from the insertion point of the patella tendon to two points on the proposed osteotomy line (perpendicular to the cranial border of the tibial crest and at the joint surface) was the most accurate (Mossman et al. 2015).

High-quality, well-positioned mediolateral and caudocranial radiographic views of the tibia, including the stifle and hock joints, are necessary for preoperative planning: mediolateral to measure the tibial plateau angle, determine the appropriate saw blade size, identify the appropriate osteotomy location, quantify the magnitude of required tibial plateau rotation, and

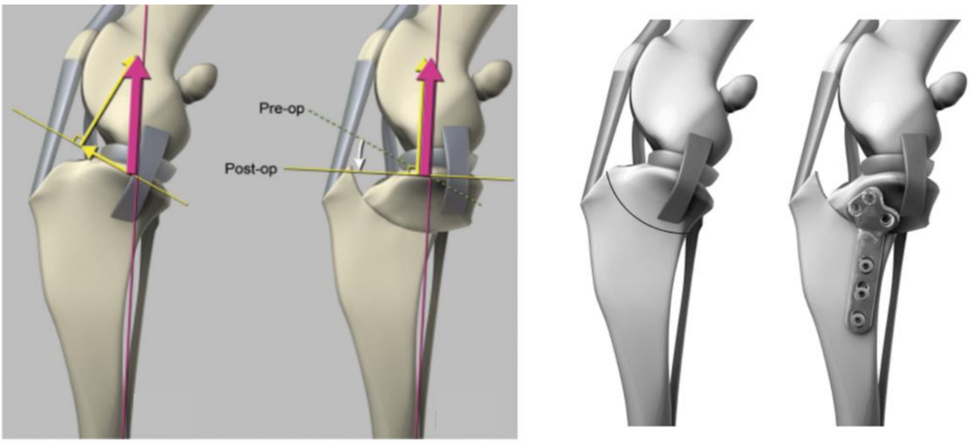


Figure 7. Illustration of the theory proposed by Slocum in 1993 and the Tibial Plateau Levelling Osteotomy. Adaptation from Tinga and Kim 2008

confirm that the entire rotation is within safe, acceptable limit (Kowaleski et al. 2012); caudocranial to screen for the presence or absence of angular or rotational deformities and measure their magnitude if present, and to identify the location of the fibular head with respect to the joint surface for intraoperative reference (Kowaleski et al. 2012).

A significant linear correlation between preoperative planned magnitude of rotation and postoperative TPA has been detected (Windolf et al. 2008), nevertheless, it is a challenging technique and requires great accuracy when executing the osteotomy and rotation of the tibial fragment to precisely obtain the desired postoperative TPA (Schaefer 2017).

TPLO technique is associated with high short and long-term success rates in both small and large dogs, and it is more likely to be associated with full functional outcomes when compared with TTA surgery (Conzemius et al. 2005; Christopher et al. 2013; Schaefer 2017).

5. COMPLICATIONS ASSOCIATED WITH TIBIAL PLATEAU LEVELLING OSTEOTOMY

Complications associated with the TPLO procedure are well-documented with different rates and types of complications having been described in the literature. They include incisional complications (inflammation, drainage, swelling, seroma and infection), patellar tendonitis, medial patellar luxation, “pivot shift”, subsequent meniscal tear, infection, implant failure, delayed bone healing, tibial or fibular fracture, osteosarcoma and progression of degenerative joint disease (Pacchiana et al. 2003; Stauffer et al. 2006; Fitzpatrick and Solano 2010; Gatineau et al. 2011; Kowaleski et al. 2013; Oxley et al. 2013; Griffon 2016a).

Usually, complications are defined as any undesirable outcome associated with the surgical procedure and can be classified depending on severity as major (surgical intervention required or lameness for >12 weeks) or minor (managed nonsurgically) (Fitzpatrick and Solano 2010). Incisional complications and infections represent the majority of complications and usually do not need surgical treatment. Major complications, which requires a second surgery, include subsequent meniscal tear, infection, osteomyelitis, tibial fractures and implant failure (Pacchiana et al. 2003; Stauffer et al. 2006; Fitzpatrick and Solano 2010; Hans et al. 2017).

Pacchiana et al. (2003), in a study involving 397 TPLO procedures, reported a 28% complication rate with 37% of major complications and 67% of minor complications. Another study reported a complication rate of 20.6% on 253 procedures, with higher incidence of complications (40%) in dogs with bilateral TPLO procedure performed under a single anaesthetic time (Priddy et al. 2003). In a study involving 696 TPLO surgeries the overall complication rate reported was 18.8% (Stauffer et al. 2006).

More recently, Fitzpatrick and Solano (2010), in a study with 1146 TPLO surgeries, reported an overall complication rate of 14.8% with 6.6% of major complications such as subsequent meniscal tear, plate removal with or without positive microbial culture and tibial tuberosity fracture. In 2011, Gatineau et al. in a retrospective study of 476 TPLO procedures reported a complication rate of 9.7%. Several other studies reveal lower rates of TPLO complications, varying from 9.7% to 14.8% (Fitzpatrick and Solano 2010; Gatineau et al. 2011; Kowaleski et al. 2013; Oxley et al. 2013), while still others find higher complications rates such as 27.8% or 36% (Garnett and Daye 2014; Hans et al. 2017). Ultimately, the comparison between different studies can be very difficult because of the inconsistent categorization, inadequately detailed reporting, and, in many cases, low rates of long-term follow-up (Oxley et al. 2013).

Factors such as increased age, body weight, breed, complete preoperative CrCL rupture, TPA, narrow tuberosity width and surgeon’s experience may predispose to complications (Pacchiana et al. 2003; Bergh et al. 2008; Fitzpatrick and Solano 2010; Gatineau et al. 2011; Taylor et al. 2011; Bergh and Peirone 2012).

5.1 Degenerative joint disease

Degenerative joint disease (DJD) is the result of mechanical and biologic events that destabilize the normal balance of degradation and synthesis of articular cartilage and subchondral bone, affecting the chondrocytes and surrounding matrix and ultimately leading to morphologic, biochemical, molecular, and biomechanical changes. DJD can cause pain, decreased range of motion (ROM), crepitus, and variable degree of inflammation (Ragetly and Griffon 2016).

DJD is a common disease in small animals and can be already present in cases of CrCL rupture at the time of surgery. However, iatrogenic articular damage, an injury to the cartilage caused by a diagnostic or therapeutic procedure, maybe a complication in cases where DJD was not present previously or can aggravate the condition in cases that already had degenerative changes. Although, largely unreported, iatrogenic articular damage can be the most common surgical complication leading to DJD. The damage can result from direct trauma to the cartilage surface, which may occur during intraarticular surgery (arthrotomy or arthroscopy) or secondary to penetration of an implant in the subchondral bone or in the deeper layer of the cartilage, compromising the tissue biomechanics (Ragetly and Griffon 2016). Initial studies on TPLO complications observed 0.5-1% of intraarticular screw placement (Pacchiana et al. 2003; Priddy et al. 2003) and, more recently, Kowaleski et al. (2013) reported 3.6% in a study of 56 TPLO procedures. Implant migration, failure to achieve joint stabilization by either incorrect reduction of the osteotomy or implant failure, meniscectomy and meniscal release are also factors that contribute to the progression of DJD (Cook et al. 2010; Ragetly and Griffon 2016).

Progression of DJD is a common complication after surgical treatment for CrCL rupture, probably because treatment is not initiated before secondary changes occur in the affected joint. Also because the surgery acts on the cause but cannot correct secondary degenerative changes, allowing the breakdown cycle of articular cartilage (Griffon 2016). Normally, this progression occurs despite an acceptable clinical outcome, being reported to occur in 40% to 76% of dogs after TPLO (Rayward et al. 2004; Lineberger et al. 2005; Boyd et al. 2007; Hurley et al. 2007). However, the presence of DJD does not correlate with clinical function, so the radiographic outcome should be used with caution as a predictor of clinical outcome (Gordon et al. 2003). And in all cases, long-term medical management should be considered (Ragetly and Griffon 2016).

5.2 Infection

Surgical wound infection is the most common cause of postoperative morbidity, and it can cause serious complications after surgery. In small animals, the overall postoperative wound infection rate ranges from 5.1% to 5.8% (Vasseur et al. 1988; Eugster et al. 2004). However, surgical wound infection is not very well defined. In human medicine, surgical site infection is defined as one that occurs within 30 days after a surgical operation or within 1 year if a surgical implant was left in place after the procedure. In veterinary medicine, surgical site infection (SSI) (term adapted from the human medicine by Frey et al. 2010) is defined as infected if there is a purulent discharge from the wound within 14 days after surgery and in some studies, it can also include signs typical of infections such as redness, pain, swelling, and heat (Laitinen-Vapaavuori 2016).

The classification of surgical procedures has been based on the degree of bacterial contamination and defines 4 categories: clean, clean-contaminated, contaminated and dirty. A clean surgical procedure is a nontraumatic, noninflamed operative wound with no entry into the gastrointestinal (GI), urogenital, respiratory tracts or oropharyngeal cavity; in a clean-contaminated surgery there is an entry into the GI, urogenital, respiratory tracts or oropharyngeal cavity or it is a clean procedure in which a drain is placed or there was a minor break in aseptic technique; a contaminated surgery occurs when there is a fresh traumatic wound (<4 hours old) or spillage from the GI or urogenital tract or a major break in aseptic technique; in a dirty surgical procedure there is an acute bacterial infection encountered, such as in a traumatic (>4 hours old) wound with devitalized tissues or foreign bodies or faecal contamination (Laitinen-Vapaavuori 2016). Infection rates for each category have been reported: 2.5% to 4.9% in clean wounds, 4.5% to 5.9% in clean contaminated wounds, 5.8% to 12.0% in contaminated wounds, and 10.1% to 18.1% in dirty wounds (Vasseur et al. 1988; Brown et al. 1997; Nicholson et al. 2002; Eugster et al. 2004).

Risk factors include patient-related factors, such as age, body weight (Eugster et al. 2004; Frey et al. 2010), nutritional status (malnutrition, low serum albumin levels or postoperative hyperglycemia) or altered immune status (preexisting infection or colonization with microorganisms) (Mangram et al. 1999; Moucha et al. 2011; Nazarali et al. 2015), and those that are operation-related, such as duration of surgical scrub, preoperative clipping and skin preparation (Brown et al. 1997), duration of surgery (Vasseur et al. 1988; Brown et al. 1997; Nicholson et al. 2002; Eugster et al. 2004) and anesthesia (Beal et al. 2000; Nicholson et al. 2002; Eugster et al. 2004; Frey et al. 2010; Nazarali et al. 2014), number of persons in the operating room (Eugster et al. 2004), antimicrobial prophylaxis, inadequate sterilization of instruments, foreign material in surgical site and surgical technique (Laitinen-Vapaavuori

2016). Because the causative agent is most often endogenous and the patient's skin is a major source of pathogens that cause wound infections, optimization of preoperative skin antisepsis is important. Although, it was concluded, in a metaanalysis, that preoperative cleansing with chlorhexidine is superior to povidone–iodine in reducing postoperative SSI after clean-contaminated surgery (Noorani et al. 2010), a recent study demonstrated that there is no difference between either pre surgical asepsis protocols. In this study, the authors showed that use of 7.5% povidone-iodine or an alcoholic solution of 2% chlorhexidine appears to have similar efficacy in reducing the total load of skin bacteria and preventing surgical site infections in dogs undergoing surgery (Belo et al. 2018).

Diagnosis is based on clinical signs, such as purulent discharge, redness, swelling, heat, and pain or discomfort, and possible positive bacterial culture. If only redness, swelling, or heat is present, it is necessary to differentiate from the normal inflammatory response that occurs in early wound healing and that normally subside within 24 to 48h after surgery (Laitinen-Vapaavuori 2016). Systemic signs may also be present and include fever, tachypnea, and leukocytosis with a left shift. If the infection involves the bone, a radiographic examination may be warranted, and signs of osteomyelitis may be identified (Laitinen-Vapaavuori 2016).

Osteomyelitis is an inflammation of the bone, typically due to an infectious process caused by bacteria or fungi, and can be classified, based on its origin, as hematogenous or posttraumatic. Posttraumatic osteomyelitis can result from direct inoculation of infectious agents during trauma or surgery or often resulting from an initial wound infection that gradually extends from the soft tissues into the bone (Laitinen-Vapaavuori 2016). The diagnosis is based on the clinical signs combined with radiographic signs, such as the presence of a well-defined segment of bone with increased radiopacity, consistent with a sequestrum, evidence of bone resorption and implant failure, or microbiologic testing. Soft tissue swelling may appear radiographically within 24 to 48 hours, but bony changes are delayed by at least 10 to 14 days, so radiographs are especially helpful to diagnose chronic osteomyelitis (Laitinen-Vapaavuori 2016).

The treatment of SSI consists of surgical drainage or wound debridement, depending on the extent of tissue involvement and an appropriate antimicrobial therapy, which should be based on bacterial culture results. In more severe cases, where osteomyelitis is present, implants may be removed, cultures obtained from deep tissues and long-term antibiotic treatment (minimum 6 weeks) is required. The prognosis is good for superficial infections, however if infection involves deep tissues or bone, it can seriously affect the outcome of the surgery. In any case, SSI may prolong recovery time, causing discomfort to the patient and increasing the costs of the treatment (Laitinen-Vapaavuori 2016).

Therefore, SSI and especially osteomyelitis is one of the most challenging complications after an orthopedic surgery and surgeons have become more aware of the risk of osteomyelitis after TPLO, which seems higher than after other elective orthopedic procedures (Laitinen-Vapaavuori 2016). In a retrospective study of 253 TPLO, osteomyelitis was reported as the single most common complication (Priddy et al. 2003). Several studies reported SSI rates, ranging from 3% to 14% (Cook et al. 2010; Fitzpatrick and Solano 2010; Frey et al. 2010; Gatineau et al. 2011; Nazarali et al. 2014; Nazarali et al. 2015; Brown et al. 2016) and the most common organisms isolated include gram-positive organisms, with *Staphylococcus spp* being the most common bacteria (Fitzpatrick and Solano 2010; Nazarali et al. 2014; Brown et al. 2016). Fitzpatrick and Solano (2010) reported, in a study with 1000 TPLO, 6.6% of infections, where 30.3% needed implant removal with *S. aureus* being the most frequent organism and 18.7% being methicillin resistant (MRSA). In Nazarali et al. (2014) SSI was documented in 13.3% of dogs with 80% of the cases needing implant removal. In this study, the most frequent organism was *S. pseudintermedius* (88.2%; n=15) where 40% (n=4) were methicillin resistant (MRSP). Surgeons' awareness of SSI's importance has been forced by its unexpectedly high prevalence, as well as by the emergence of methicillin resistant bacteria (Laitinen-Vapaavuori 2016).

Prophylactic antibiotherapy is justified by the duration of surgery, placement of implants and pre-existing compromise of trauma patients (Laitinen-Vapaavuori 2016) and has been reported as a protective factor against SSI (Eugster et al. 2004). Also, a study with 902 TPLOs found that dogs that did not receive postoperative antibiotherapy were 4 times more likely to develop SSI than dogs that received it (Frey et al. 2010). The decreased risk of SSI with association of postoperative antibiotherapy was also reported by other authors (Fitzpatrick and Solano 2010; Nazarali et al. 2014), in which the probability of developing postoperative infections in a dog that received postoperative antibiotics was half that of a dog that did not receive such treatment (Fitzpatrick and Solano 2010). The cause of these findings may be related to early treatment of undiagnosed postoperative infection and control of postoperative contamination (Laitinen-Vapaavuori 2016).

5.3 Delayed bone healing

Fractures that do not heal as quickly as expected based on biologic, mechanical and clinical factors are considered delayed unions. Adult dogs should have radiographic evidence of fracture healing by 12 weeks and immature dogs by 6 weeks (Johnson 2016). The anticipated rate of fracture healing should take into consideration several factors, such as, the location of the fracture, the nature of the traumatic injury, the animal's systemic state, the fracture´s fixation, and postoperative management (Hayda et al. 1998). The risk factors for the occurrence of this complication include systemic illness, compromised vascular supply, unstable implants, extremely rigid fixation, infection, poor postoperative management and pharmacologic factors such as the use of corticosteroids and NSAIDs. Although, long-term postoperative administration of carprofen seems to inhibit the bone healing in tibial osteotomies in dogs (Ochi et al. 2011), the benefits of short-term postoperative administration of NSAIDs may outweigh their potential and transient effect on fracture healing (Griffon 2010).

Although weight bearing and pain response to palpation at the fracture site are important clinical signs, radiography is the standard method for evaluating bone healing. Normally, fractures that are not healed by 12 to 16 weeks and have evidence of progressive healing activity but with a doubtful outcome are diagnosed as delayed unions (Johnson 2016). Treatment will depend on the stability and potential longevity of the fixation. If there is no evidence of impending failure of the implants and there is evidence of bone healing, conservative treatment is the option with continued confinement and serial evaluations. If there is minimal progression of healing a cancellous bone autograft or allograft with demineralized bone matrix may be inserted surgically (Hoffer et al. 2008). In cases where fixation is unstable, it should be modified or replaced, in this case, bone graft is recommended (Johnson 2016).

5.4 Subsequent meniscal tear

Subsequent meniscal tear is a meniscal injury that was not diagnosed during initial treatment and then it is detected postoperatively. Subsequent tears are thought to occur secondary to residual instability, as a result of failure to correct all abnormal forces acting on the stifle after stabilization surgery and may result in persistent lameness requiring additional surgical treatment (Case et al. 2008). This condition is one of the most common major complications after CrCL rupture repair surgery, with an overall incidence ranging from 0.7% to 13% (Thieman et al. 2006; Duerr et al. 2008; Cook et al. 2010; Fitzpatrick and Solano 2010; Gatineau et al. 2011; Christopher et al. 2013; Ritzo et al. 2014). Of all meniscal tears, the most common are the bucket handle tears affecting the medial meniscus (76%), whereas lesions such as frayed caudal horn tears of the medial meniscus (20%) and longitudinal tears of the lateral meniscus (3%) are less common (Case et al. 2008).

Dogs with postoperative meniscal tear are typically presented for persistent lameness, failure to progress to expected levels of function, or acute onset of lameness. Pain during flexion and extension of the stifle can increase the odds of having a medial meniscal disease in 4.3 times and detection of an audible click can increase the likelihood of the disease by a factor of 11.3 (Dillon et al. 2014). The definitive diagnosis is made by direct inspection through arthrotomy or, preferably, by second-look arthroscopy (Griffon 2016a). A partial meniscectomy (removal of a damaged portion involving less than half of the meniscus), hemi-meniscectomy (removal of the caudal pole of the meniscus), or complete meniscectomy, can be performed, depending on type and grade of the lesion, by arthroscopy or arthrotomy improving or resolving lameness in 96% of cases (Case et al. 2008). Meniscectomy alters the biomechanics of the stifle, compromising the function of the meniscus resulting in stress concentration which may predispose to osteoarthritis and progression of DJD (Bergh et al. 2008; Pozzi et al. 2008a), therefore medical management should be prescribed after surgery (Griffon 2016a). Medial meniscectomy was also reported as a risk factor for “pivot shift” (Gatineau et al. 2011).

To prevent the postliminary meniscal tears is important to optimizing the surgical diagnosis of pre-existing lesions, preferably by arthroscopy with probing (Pozzi et al. 2008b; Ritzo et al. 2014). Medial meniscal release has been proposed as a preventive measure for subsequent meniscal tears after TPLO, allowing the medial meniscus to move away from the crush exerted by the medial femoral condyle during cranial translation of the tibia. Caudal meniscal release via transection of the caudal meniscotibial ligament is preferred over a radial release. However, the efficacy of this procedure remains controversial. Recently, it was found effective at decreasing the risk of postliminary meniscal disease in a clinical study (Ritzo et al. 2014), while other studies report that this procedure does not reduce the rate of subsequent meniscal tear (Thieman et al. 2009), and that meniscal release alone is associated with articular loss, further meniscal pathology, lameness and progression of degenerative joint disease (A Pozzi et al. 2008; Luther et al. 2009).

5.5 Osteosarcoma

A fracture-associated sarcoma is a primary tumour of bone that arises at a previous fracture site, possibly secondary to the original trauma or placement of implants, and plate fixation is most commonly associated with this condition (Pluhar 2016).

Histologically, osteosarcomas are the most commonly reported tumours, although undifferentiated sarcomas, fibrosarcomas, and other tumour types have also been described. Implant-associated sarcomas have been reported after tibial plateau levelling osteotomy (TPLO), independent of traumatic fractures (Pluhar 2016). Some studies document sarcomas of the proximal tibia in dogs after TPLO (Boudrieau et al. 2005; Harasen and Simko 2008; Atherton and Arthurs 2012; Selmic et al. 2014; Selmic et al. 2018). Although the reported incidence of osteosarcoma after TPLO is rare, 1 in 100 dogs over 12 years (Pluhar 2016), dogs undergoing bilateral TPLO are 8.4 times more likely to develop a tumour (Sartor et al. 2014). The fact that osteosarcomas spontaneously develop in the proximal tibia makes it difficult to determine a causative relationship between TPLO and sarcoma. Nonetheless, corrosion of the stainless steel implants has been proposed to increase osteolytic activity in adjacent bone and chronic synovitis, potentially contributing to the neoplasia (Boudrieau et al. 2005; Sprecher et al. 2018). This may justify the removal of TPLO plates after clinical union of the osteotomy (Pluhar 2016).

The most common clinical signs include lameness, pain, and soft tissue swelling over the surgical site. However, non–weight-bearing lameness, instability, and crepitus may also be present if a pathologic fracture exists. These tumours are more frequent in middle and old aged dogs of large and giant breeds but can affect any breed (Pluhar 2016; Selmic et al. 2018). The treatment for fracture-associated sarcoma is normally surgical and includes amputation of the affected limb, with or without chemotherapy or more rarely, limb-sparing procedures (Selmic et al. 2014; Pluhar 2016). The prognosis is poor and the median survival time with treatment is approximately 1 year (Selmic et al. 2014). Therefore, dogs diagnosed with implant-associated sarcoma are sometimes not treated (Pluhar 2016). These tumours are found in sites of previous trauma, but the role of trauma and implants in neoplastic development is still unclear (Pluhar 2016).

5.6 Patellar tendon thickening and tendonitis

Postoperative patellar tendon thickening is an anatomic change in the dimensions of the patellar tendon after TPLO, whereas patellar tendonitis is defined as a clinical condition resulting from postoperative inflammation of the tendon (Griffon 2016a).

Patellar tendon thickening may be an accidental radiographic finding, however patellar tendonitis is associated with clinical signs. The reported incidence of this condition varies from 0.3% to 25% (Pacchiana et al. 2003; Carey et al. 2005; Stauffer et al. 2006; Conkling et al. 2010; Fitzpatrick and Solano 2010; Garnett and Daye 2014) and is higher (80% of cases) in a study on the effect of TPLOs on the patellar tendon. Despise this finding, only 7% of the dogs in this study displayed clinical signs of patellar tendonitis and most cases improved with medical management (Carey et al. 2005). Nevertheless, TPLO changes the patellar femoral joint kinematics, and this may be a predisposing factor to patellar tendonitis (Pozzi et al. 2013).

5.7 Implant failure

Implant failure constitutes implant loosening or breakage that compromise stabilization of the osteotomy and subsequent bone healing (Griffon 2016a). The risk factors for this complication include the use of non-locking screws or failure to obtain bicortical fixation, combining TPLO with cranial wedge osteotomy, excessive postoperative exercise, infection, excessive micromotion at the osteotomy site, concurrent tibial tuberosity or fibular head fractures and delayed bone healing (Griffon 2016a).

Depending on the type of implant failure and its consequence on the stability of the osteotomy, clinical signs can be absent, if a loosening screw is an accidental finding on radiographic follow-up or can be obvious, varying from discrete lameness to sudden non-weight-bearing lameness and crepitation on palpation at the osteotomy site. The diagnosis is made by radiographic examination and signs may include radiolucency around the implant, implant migration, loss of reduction of the osteotomy, delayed healing and bone fracture (Griffon 2016a).

Conservative management and exercise restriction may be considered if implant loosening is an accidental finding on follow-up radiographs in dogs with the normal progression of bone healing and stable fixation. If the stability of the osteotomy is questionable or bone healing appears delayed revision should be considered. In case of catastrophic failure immediately surgical revision is required for replacement of the implant, loose screw or replacement with an external fixator (Griffon 2016a). The prognosis is good, although bone healing may be delayed. Implant failure is an infrequent complication reported in only 2% of cases and, mostly, results from an inadequate technique for plate contouring, failure to obtain bicortical screw fixation or failure on the postoperative exercise restriction (Griffon 2016a).

5.8 Bone fractures

Bone fractures secondary to TPLO include fractures of the fibula, tibial tuberosity and tibia. The incidence varies among studies with a mean incidence of 1.2%, 3%, and 3.2%, respectively (Griffon 2016a). In a retrospective study of 213 TPLOs, tibial tuberosity avulsion fractures were reported in 4% of the cases (Bergh et al. 2008). The incidence of fibular fracture has been reported at 5.4% in a study of 168 TPLOs (Tuttle and Manley 2009) and, more recently, 15 % in a study of 355 TPLOs (Taylor et al. 2011). Tibial fractures, although uncommon, are a major complication after TPLO (Griffon 2016a).

Tibial tuberosity fractures may result from tension applied by the quadriceps on the patellar tendon and cranial tibial osteotomy, simultaneous bilateral TPLO, placement of an anti-rotational holding pin perpendicular to the long axis of the tibia, correction of steep TPA (≥34º), and previous extracapsular repair with a hole or a tunnel drilled in the proximal tibia, are described as risk factors for this type of complication (Griffon 2016a). The risk factors reported for fibular fractures include increased body weight, steep preoperative TPA and magnitude of the TPA correction, presence of a drill hole in the fibula and TPLO performed without a jig (Tuttle and Manley 2009; Taylor et al. 2011). Both tibial tuberosity and fibular fractures are normally confirmed on routine follow-up radiographs. Tibial tuberosity fractures may be associated with delayed return to function, swelling, and pain over the tibial crest. Fibular fractures may occur intraoperatively, however, they are generally an incidental finding, and most fractures occur at the fibular neck level, some involving the body, and more rarely can affect the fibular head (Griffon 2016a).

Tibial tuberosity and fibular fractures are normally treated conservatively if they do not appear to affect implant stability or bone healing. Unstable tibial tuberosity fractures, if diagnosed early, can be treated with a tension band to avoid secondary implant failure. Tibial fractures are a major complication, generally combined with implant failure, inducing non-weight-bearing lameness and requiring surgical revision and treatment of any concurrent disease, such as infection. The treatment aims to restore stability on the osteotomy site and the ability of the tibia to sustain the biomechanical load, and can be achieved with plate fixation, external fixation, or a combination of both (Griffon 2016a).

The outcome of the tibial tuberosity and fibular fractures are very good if stability is maintained until bone union, for tibial fractures the prognosis is more variable, depending on the type and location of the fracture, ability to restore stability, and presence of infection (Griffon 2016a).

II. MATERIALS AND METHODS

1. Objectives and inclusion criteria

The aim of the study was 1) to describe the short-term complications associated with TPLO for treatment of CrCL rupture, and 2) to identify factors that may have an influence its occurrence.

Medical records of 77 dogs (101 stifles) that underwent a standard TPLO for CrCL rupture at Centre Hospitalier Vétérinaire Frégis (CHV-Frégis) at Paris Arcueil, performed by a ECVS surgeon or by a 3rd or 2nd year resident surgeon under supervision of an ECVS surgeon, between April 2015 and January 2019, were reviewed. Of these 51 dogs (68 stifles) had at least one postoperative follow-up record, and 30 dogs (38 stifles), at least two 2 follow-ups at 4 weeks and 8 weeks postoperative. For comparison purposes only the latter 30 were selected for inclusion in the study. Variables obtained from the medical record included information regarding clinical signs, radiographic films, details of surgical procedure, intra and postoperatively complications and follow-up examinations.

2. Signalment

Data obtained from medical records included breed, sex, age, affected limb, stifle radiograph findings, partial versus complete CrCL rupture, degree of lameness, unilateral versus bilateral CrCL rupture, and presence of meniscal tear. Treatment for meniscal damage, implant type and postoperative TPA were also reported. Contralateral CrCL rupture was documented and time between the diagnosis of the two CrCL ruptures was measured. Any complications following surgery were recorded.

3. Radiographic assessment

All dogs had the affected stifle assessed radiographically and the presence of signs of joint effusion and arthrosis were reported. Standard mediolateral and caudocranial radiographic projections were obtained. Mediolateral radiographs centred on the stifle but including the tarsus were taken for measurement of the preoperative TPA. For that purpose, major importance was given to obtain a radiograph in which the femoral condyles overlapped each other. Sandbags or foam wedges were used when necessary. Projections were repeated if complete superimposition of the femoral condyles on the mediolateral projection was not achieved. Postoperative caudocranial and mediolateral radiographic projections were also assessed for completeness of osteotomy reduction and surgical implant positioning (plate(s) and screws). Osteotomy healing and progression of OA were assessed subjectively by evaluation of the 4 and 8 week follow-up radiographs with caudocranial and mediolateral projections of the stifle joint (figure 8).

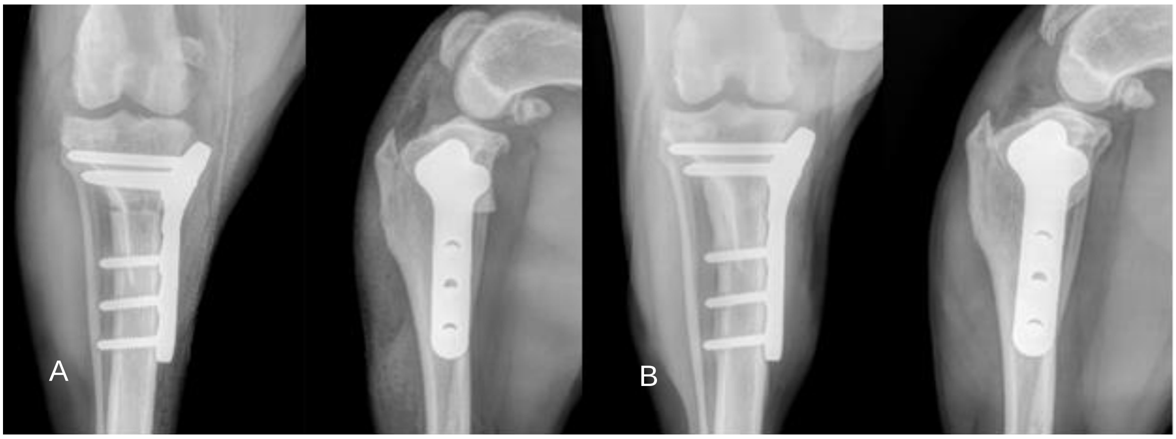


Figure 8. Mediolateral and craniocaudal view radiographs of the right stifle of one dog that underwent TPLO at CHV-Frégis: immediately after surgery (A) and 8 weeks postoperatively (B), with evidence of bone healing. Provided by CHV-Frégis.

4. Procedures

4.1 Measurement of the TPA, D1 and D2 and magnitude of rotation

All dogs that underwent TPLO had preoperative TPA measurements. The preoperative TPA was determined from a lateral radiographic view of the tibia which included both stifle and tarsus joints, with the X-ray beam centred on the stifle joint. The functional tibial axis line was drawn, passing through a point at the centre of the talus and a point at the centre of the intercondylar eminences; the medial tibial plateau line was drawn, connecting the cranial aspect of the medial tibial plateau to the caudal aspect of the medial tibial plateau line; a reference line was drawn, perpendicular to the functional tibial axis line; and finally the angle between the medial tibial plateau line and the reference line was measured corresponding to the TPA (figure 9). D1 and D2 are measured from the point at which the patellar ligament

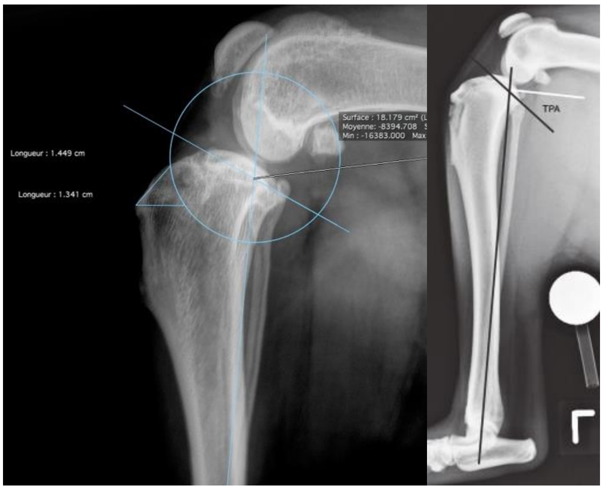


Figure 9. Measurement TPA and D1 and D2. Provided by CHV-Frégis and adaptation from Kowaleski et al. 2012

inserts on the tibial tuberosity (figure 9). D1 is measured along the cranioproximal border of the tibia and equal the distance from the patellar ligament insertion to the point at which the intended osteotomy exited the tibia. D2 is measured along a line perpendicular to the cranial border of the tibial crest and equal the distance from the patellar ligament insertion to the intended osteotomy. The magnitude of rotation of the tibial plateau in millimeters is determined from a TPLO chart designed to achieve a 5º postoperative tibial plateau angle to estimate the final position of the tibial plateau segment.

4.2 Preoperative management

All dogs had radiographic assessment done on the day immediately before surgery, for preoperative TPA measurement and preoperative planning, such as selection of saw blade size, appropriate osteotomy location and to quantify the magnitude of required tibial plateau rotation (Table 1).

Table 1. Quick reference chart for TPLO rotation from DePuy Synthes Vet – www.synthesvet.com

Saw Radius	15°	16°	17°	18°	19°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	30°	31°	32°	33°	34°	35°	36°	37°	38°	39°	40°
	Rotation (mm) — Provides Resultant 5° TPA																									
12 mm	2.0	2.2	2.4	2.6	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.3	6.4	6.6	6.8	7.0
15 mm	2.6	2.8	3.1	3.3	3.6	3.8	4.1	4.3	4.6	4.9	5.1	5.4	5.6	5.9	6.1	6.4	6.6	6.9	7.1	7.4	7.6	7.9	8.1	8.4	8.6	8.8
18 mm	3.1	3.4	3.7	4.0	4.3	4.6	4.9	5.2	5.5	5.8	6.1	6.5	6.8	7.1	7.4	7.7	8.0	8.3	8.6	8.9	9.2	9.5	9.8	10.1	10.3	10.6
21 mm	3.6	4.0	4.3	4.7	5.0	5.4	5.8	6.1	6.5	6.8	7.2	7.5	7.9	8.3	8.6	9.0	9.3	9.7	10.0	10.4	10.7	11.1	11.4	11.8	12.1	12.4
24 mm	4.1	4.5	5.0	5.4	5.8	6.2	6.6	7.0	7.4	7.8	8.2	8.6	9.0	9.5	9.9	10.3	10.7	11.1	11.5	11.9	12.3	12.7	13.1	13.5	13.9	14.3
27 mm	4.7	5.1	5.6	6.0	6.5	7.0	7.4	7.9	8.4	8.8	9.3	9.7	10.2	10.6	11.1	11.6	12.0	12.5	12.9	13.4	13.8	14.3	14.7	15.2	15.6	16.1
30 mm	5.2	5.7	6.2	6.7	7.2	7.8	8.3	8.8	9.3	9.8	10.3	10.8	11.3	11.8	12.3	12.9	13.4	13.9	14.4	14.9	15.4	15.9	16.4	16.9	17.4	17.9

In the preoperative period, the pre-medication routinely administered was morphine (0.2 mg/kg, slow IV) and diazepam (0.2 mg/kg, IV). General anesthesia was induced with propofol and maintained with isoflurane. Cefazolin (15 mg/kg) was administered 20 minutes before surgery and repeated every 90 minutes during surgery. The limb was clipped from the greater trochanter to the level of the metatarsus and a scrub was performed by a gloved assistant with a solution consisting of 2% chlorhexidine for approximately 5 minutes until the skin appeared clean. After transfer to the theatre, the dog was positioned in dorsal recumbency with the pelvic limb hanging and then chlorhexidine spray was applied.

4.3 Surgical Technique

Exploration of the stifle joint before TPLO surgery was performed by craniomedial arthrotomy allowing examination of the intra-articular structures, and evaluation of the CrCL's degree of damage (complete or partial rupture) and presence of degenerative joint disease. Remnants of the CrCL were removed, the menisci were assessed for any injuries and whenever meniscal damage was present, debridement by partial or complete meniscectomy was performed. The incision was extended to expose the medial proximal tibia, the joint surface was identified by probing with a 25-gauge needle progressively from distal to proximal in the middle of the collateral ligament until the needle entered the joint space. A 12 to 15 mm incision was made caudal to the medial edge of the patellar ligament to expose the infrapatellar bursa and the straight end of a Senn retractor (or similar instrument) was placed in the bursa to retract the patellar ligament. Electrocautery was used to mark the location of distances D1 and D2 on the tibial surface (figure 10). A tibial plateau levelling osteotomy saw blade of appropriate size was selected and placed on the tibia such that its convex surface passed through both marks at D1 and D2. At this moment, the osteotomy was accurately placed on the tibia according to the preoperative planning.

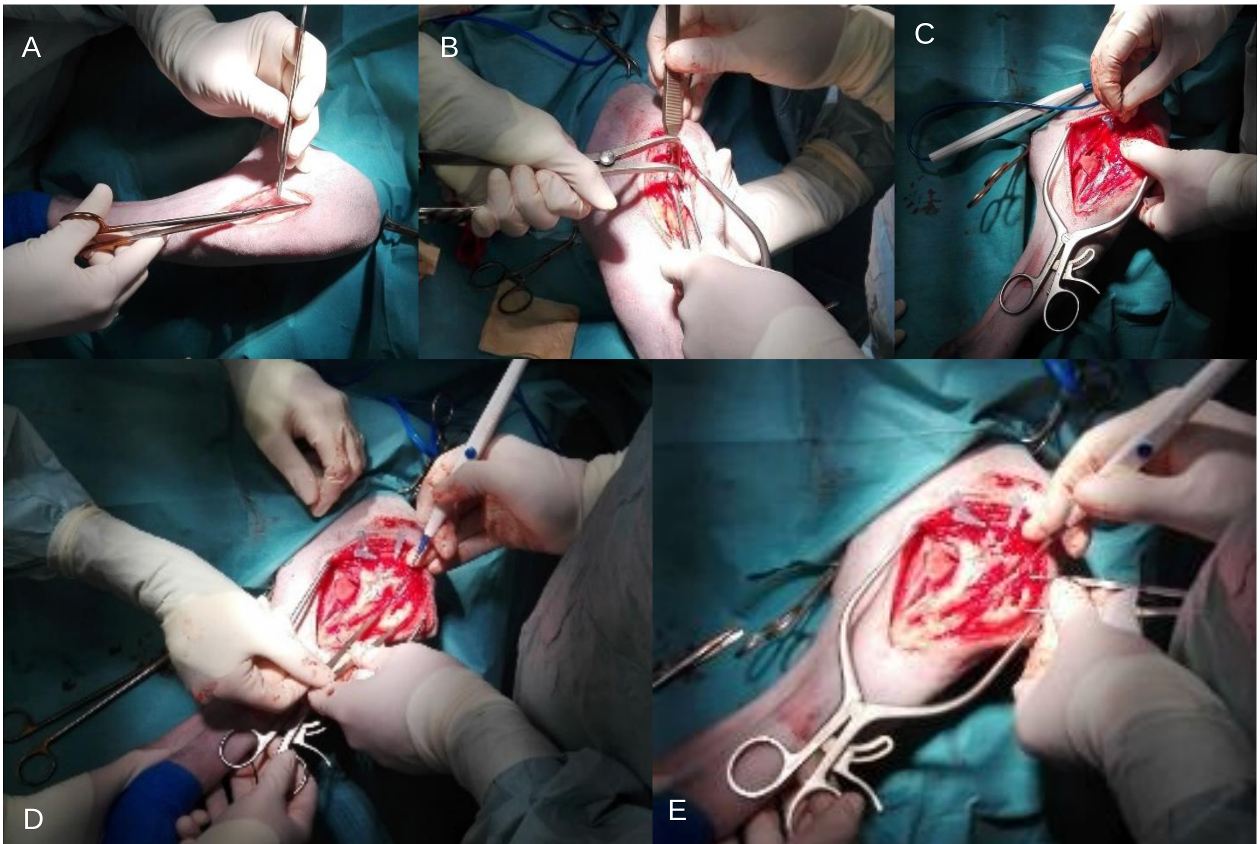


Figure 10. First steps of the **s**urgical procedure: Incision on the medial proximal tibia (A); Arthrotomy and examination of the structures in the stifle joint (B); the joint surface identified by probing with a 25-gauge needle (C); the location of distances D1 and D2 marked on the tibial surface with un electrocautery (D e E). Provided by CHV-Frégis.

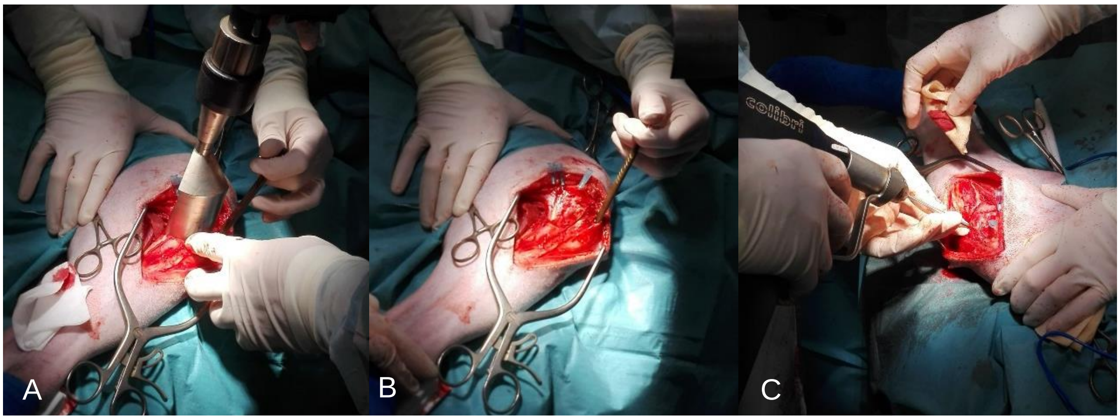


Figure 11. Some steps of TPLO surgery: Osteotomy (A and B); Placement of a pin to use as a rotation pin (C). Provided by CHV-Frégis.

The osteotomy was performed approximately one half of the way across the tibia, some periosteum was excised adjacent to the osteotomy on both tibial segments, the rotation distance was marked with an osteotome and could be highlighted with electrocautery to make them easier to discern. The osteotomy was completed with assurance that the correct orientation was maintained, a pin was placed to use as a rotation pin in the tibial plateau segment and the tibial plateau segment was rotated and aligned with the rotation marks (figure

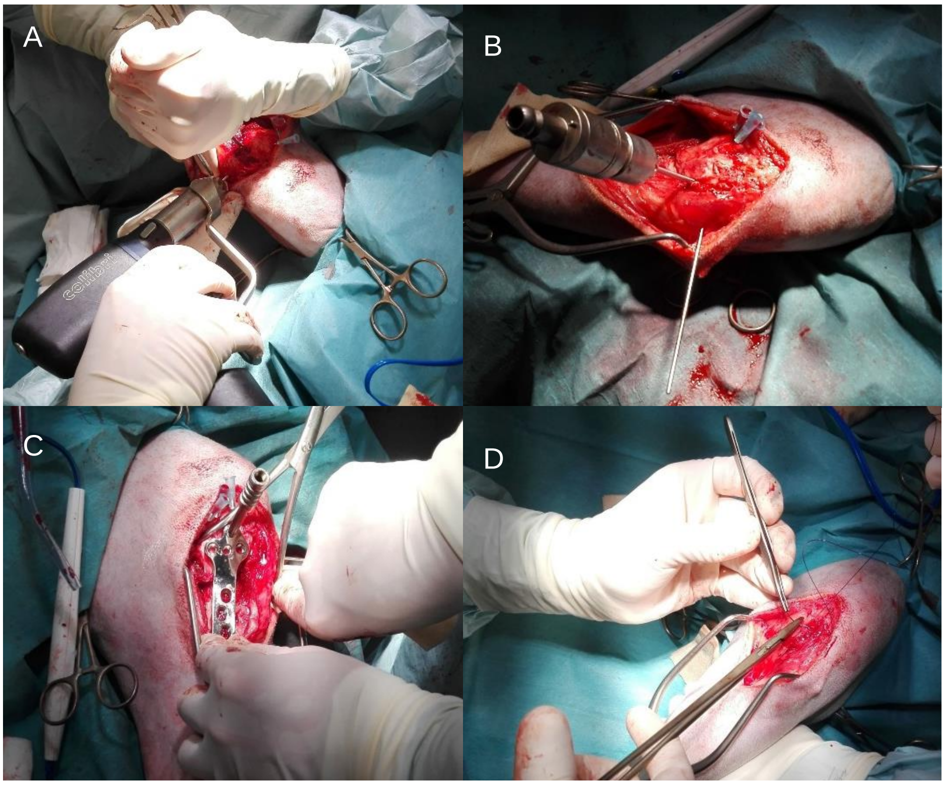


Figure 12. Some steps of TPLO surgery: Rotation and alignment of the tibial plateau segment and placement of a Kirschner wire (A and B); Placement and fixation of the TPLO implant (C); Closure of surgical site (D). Provided by CHV-Frégis.

11). A Kirschner wire was placed through the tibial tuberosity into the tibial plateau segment and a tibial plateau levelling osteotomy plate was applied with standard internal fixation techniques (figure 12).

Meticulous closure of the muscles to the fascia along the craniomedial border of the tibial crest was performed to aid in securing soft tissue coverage of the metallic implants and the subcutaneous tissues and skin were closed routinely. Postoperative radiographs were obtained and osteotomy alignment and apposition as well as implant position and limb alignment were evaluated.

4.4 Postoperative management

All dogs had another dose of morphine (0.2 mg/kg slow IV) 4 hours after the previous one given at pre-medication and continuously in intervals of 4 hours, and another dose of cefazolin (15 mg/kg) every 6 hours. The following day oral medication was introduced and consisted of cefalexin (20 mg/kg) or amoxicillin and clavulanic acid (12.5mg/kg) twice daily for 8 days, NSAIDs at the recommended dose for 14 -21 days, and in some cases tramadol (2-5 mg/kg) twice a day for 8 -14 days. Dogs were typically discharged from the hospital 12-24 hours after surgery. Upon discharge, the patient’s homecare was thoroughly discussed with the owner to allow understanding of exercise restriction, analgesia and wound care. Strict rest was recommended during the four weeks after surgery, small walks for five minutes three times daily the following week and then longer walks/exercise of ten to fifteen minutes twice to three times daily for the 3 weeks after that. Cold therapy two or three times a day during 5 min in the first 3-5 days after surgery and diet j/d from Hills® (for joint care) were also recommended.

All dogs were supposed to return at 14 days after surgery, for skin suture removal or could go to their regular veterinary clinician. However, owners were encouraged to bring their dogs for clinical examination if there was any concern. At 4 and 8 weeks following surgery, radiographic examination was performed to evaluate healing status of the osteotomy site and progression of OA, which was subjectively characterised by the veterinary surgeon based on comparison of radiographs with those taken immediately after surgery. Depending on the healing status of the osteotomy site adaptations in exercise activity were suggested by the surgeon and discussed whether further radiographic assessment would be required in the future. Whenever radiographic healing was noted, a gradual increase of exercise was recommended.

4.5 Complications

Complications were defined as any unexpected and undesired outcome associated with the surgical procedure, during or after surgery, which were confirmed by direct visualization, physical or radiographic examination. Complications were also classified depending on severity in major and minor: the first were defined as those complications requiring further surgical treatment, and the second as those not requiring additional surgical intervention. Type and outcome of complications were recorded. All complications that occurred intra- and postoperatively were considered.

4.6 Statistic analysis

Statistical Analysis was performed using Microsoft ® Office Excel® for Microsoft 365 and the statistical program GraphPad Prism 9.1.0 (GraphPad Software, La Jolla California USA).

For risk factor analysis, associations between qualitative variables and presence or absence of complications were tested using X^2 tests of independence. For all analyses, a value of $P < 0.05$ was considered significant.

III. RESULTS

1. Signalment

TPLO for CrCL repair was performed in 30 dogs (38 stifles), 14 females (46.7%), of which 10 were spayed (33.3%) and 4 were intact (13.3%), and 16 males (53.3%), of which 7 were castrated (23.3%) and 9 were intact (30.0%). The mean age at time of surgery for CrCL repair was 5.2 years (range 0-11 years). There were 5 American Staffordshire Terrier and their crosses (16.7%), 3 German Shepherds and their crosses (10.0%), 2 Cane Corso (6.7%), 2 Golden Retrievers (6.7%), 2 Labrador Retrievers (6.7%) and 1 each (3.3%) of the following breeds: Bernese Mountain Dog, Border Collie, Boxer, Cairn Terrier, Chow Chow, Dutch Shepherd, Jack Russel Terrier, Korthals Griffon, Newfoundland, Portuguese Pointer, Siberian Husky, Springer Spaniel and Weimaraner. The remaining 3 dogs (10.0%) were undetermined cross breeds.

2. Radiographic and Surgical findings

TPLO was performed in 38 stifle joints (18 left [47.4%] and 20 right [52.6%]). Fourteen dogs (46.7%) had bilateral TPLO, with the second procedure performed at varying intervals after the first with a mean of 8.4 months (range 0 to 35 months). Nine patients (30%) had bilateral CrCL disease diagnosed at first radiographic examination. One case (2.6%) had a previous surgery for CrCL repair (TightRope). All 38 stifle joints were examined via arthrotomy. The degree of rupture of the CrCL was reported and complete rupture occurred in 31 cases (81.6%) and partial rupture in 7 (18.4%). Meniscal injuries were noted in 7 (18.4%) stifles, being debrided by meniscectomy. No evidence of meniscal tear was reported in 31 (81.4%) cases. Partial meniscectomy was performed in 5 cases and in 2 cases there was no information on which treatment was chosen (partial or complete). Even though the preoperative TPAs were measured in all cases they were only reported in 10 (26.3%) of the clinical records with a mean of 29.1º (range 22º to 38º). Postoperative TPAs were also measured in all cases but they were only reported in 33 cases (86.3%) with a mean of 5.8º (range 2º to 10º). From the 38 cases, 23 surgeries (60.5%) were performed by a certificated board surgeon and 15 by a 2nd or 3rd year resident student (39.5%) under supervision of the ECVS surgeon.

3. Radiographic re-evaluation and follow-up

All dogs were examined for stifle joint stability on follow up appointments and owners were questioned about lameness and function improvement. During in-hospital evaluation, the radiographic assessment of healing occurred in 18 cases (48.6%) at 8 weeks post-operatively with 19 (51.4%) still presenting a mild line of radiolucency in the osteotomy site, although, another radiographic follow-up was not requested.

The degree of lameness was also evaluated at 4 and 8 weeks follow-up (table 2). At 4 weeks only 18.9 % of cases showed no lameness at all, but in general 59.4% cases had no lameness or only “Mild” one, showing already improvements. At 8 weeks 43.2% of the cases had no lameness reported and in only in 10.8% were “Mild to Moderate” and “Moderate” lameness observed.

Table 2. Degree of lameness 4 and 8 weeks after surgery: 0 (None) No lameness is observed at a walk or trot; 1 (Mild) Lameness is present, but may only be consistently apparent at a trot; 2 (Mild to moderate) Mild lameness is obviously present at a walk and is worse at a trot; 3 (Moderate) Obvious lameness is present at both gaits; 4 (Moderate to severe) Obvious lameness is present at both gaits and may be intermittently non-weightbearing; 5 (Severe) Lameness is non-weightbearing most or all of the time.

4 Weeks					8 Weeks			
Degree	n=37	%	%	Lameness	Degree	n=37	%	%
0	7	18.9	18.9	None	0	16	43.2	43.2
1	10	27.0	40.5	Mild	1	13	35.1	45.9
1-2	5	13.5			1-2	4	10.8	
2	5	13.5	16.2	Mild to Moderate	2	2	5.4	5.4
2-3	1	2.7			2-3	0	0.0	
3	2	5.4	13.5	Moderate	3	1	2.7	5.4
3-4	3	8.1			3-4	1	2.7	
4	1	2.7	2.7	Moderate to Severe	4	0	0.0	0.0
4-5	0	0.0			4-5	0	0.0	
5	3	8.1	8.1	Severe	5	0	0.0	0.0

4. Complications

Post-operative complications were reported for 20 (52.6%) of the 38 stifle joints, in the short-term evaluation period. Of these, 6 (15.8%) were classified as major complications and 14 (36.8%) as minor complications.

Regarding the 4 weeks follow-up, complications were reported in 20 cases (52.6%) and, of these, (15.8%) were classified as major complications and 14 (36.8%) as minor. At 8 weeks follow-up, post-operative complications were reported only for 3 cases (8.1%), all classified as minor complications and all of them having already reported a minor complication in the previous follow up.

4.1 Minor complications

Minor complications included delayed wound healing, patellar tendonitis, tibial tuberosity fracture, patellar osteophyte fracture with patellar tendonitis and iatrogenic fibular fracture (table 3).

One (2.6%) iatrogenic proximal fibular fracture was reported (figure 13). One month after surgery there was some lameness and patellar tendinosis was also present, so NSAID therapy was instituted during 7days. In the next follow-up no clinical signs associated with this condition were described and at radiographic re-evaluation, 8 weeks after surgery, there was evidence of bone healing.

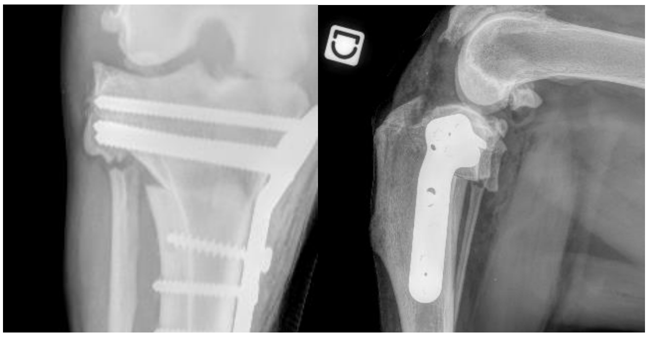


Figure 13. Iatrogenic proximal fibular fracture, radiographic re-evaluation 4 weeks after surgery. Provided by CHV-Frégis.

Five (13.2%) delayed wound healing were reported in the short-term period following surgery, in some cases associated with oedema, seroma, discharge or patellar tendonitis. The treatment varied depending on each case, included application of surgical staples, cold therapy, NSAID’s and antibiotic therapy, and it had normally been resolved by the next follow-up.

Patellar tendonitis was noted in 5 cases (13.2%) and the treatment instituted was exercise restriction, NSAIDs, physiotherapy with laser and hydrotherapy. In one case it was resolved 8 weeks after surgery, but normally took more time to completely heal.

There was one case (2.6%) of delayed bone healing associated with pivot shift. One month after surgery there was discrete bone healing and seroma. An articular punction was performed to discard infection and an NSAID and antibiotherapy was instituted, although the bacteriology analysis was negative. Two months after surgery there was still a delay in bone healing and a pivot shift was also identified, for which physiotherapy and NSAIDs were recommended.

Two fractures not requiring a second surgery were reported (figure 14), one tibial tuberosity fracture (2.6%) and one patellar osteophyte fracture (2.6%). In both cases, a patellar tendinosis was associated and more time with NSAIDs was required. In the case of patellar osteophyte fracture, physiotherapy was also recommended.

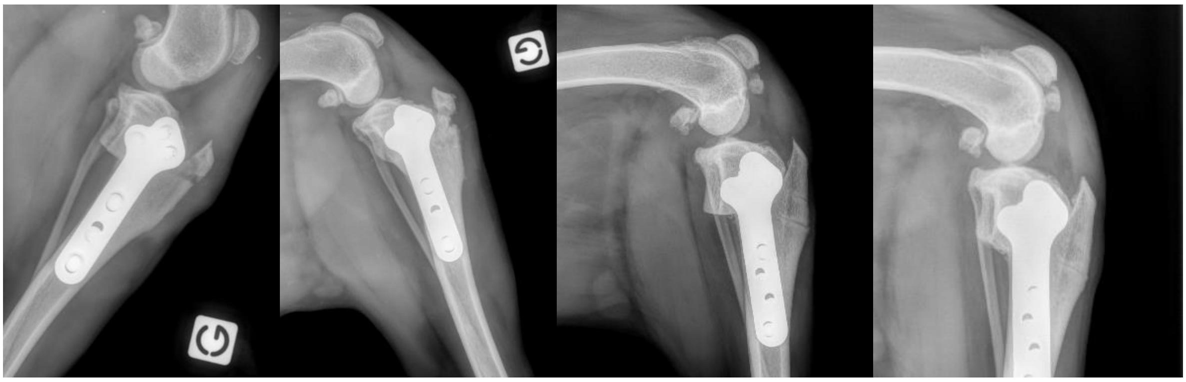


Figure 14. Tibial tuberosity fracture at 4 weeks re-evaluation (A) and 8 weeks (B); Patellar osteophyte fracture at 4 weeks follow-up (C) and 8 weeks (D). Provided by CHV-Frégis.

Table 3. Minor complications (defined as no further surgical intervention) following Tibial Plateau Levelling Ostectomy in 38 stifle joints.

Complication	Number of cases	Additional details	Treatment
Iatrogenic fibular fracture	1	Associated with patellar tendonitis	NSAIDs
Delayed wound healing	5	Associated with oedema, seroma, discharge or patellar tendonitis	Surgical staples, cold therapy, NSAID and antibiotherapy
Patellar Tendonitis	5	Lameness and discomfort/pain	Restrict exercise, NSAIDs and physio-therapy
Delayed bone healing	1	Associated with seroma. Articular punction performed to discard infection. Later pivot shift was identified	Physiotherapy and NSAIDs
Tibial tuberosity fracture	1	4 weeks after surgery fracture already healing, associated with patellar tendonitis. Possibly due to not following exercise restrictions	NSAIDs
Patellar osteo-phyte fracture	1	Associated with patellar tendonitis	NSAIDs and physio-therapy

4.2 Major complications

Major complications included three infections (7.9%) and one each (2.6%) of compartment syndrome/infection, implant failure/fracture and seroma with delayed wound healing (table 4).

There were 3 cases of infection reported. In one case, the dog was presented with oedema of the hindlimb and systemic signs of infection. A surgical procedure was performed to clean the surgical site and drains were put in place. Samples for bacterial culture and cytology were taken and the dog was treated with doxycycline. Although, the patient showed some improvement, after 11months inflammation and oedema were still present, so new surgical intervention was performed to remove the implants. These were sent for microbial culture and an antibiotic sensitivity test, which revealed presence of *Enterobacter cloacae*, and new antibiotherapy was instituted, this time with trimethoprim/sulphonamide. In a second case, the patient presented with a fistula one month after surgery. The bacterial culture was positive with growth of *Staphylococcus pseudintermedius* and the patient was treated with amoxicillin associated to clavulanic acid. In the 2 month follow-up, systemic signs of infection were present and the patient was treated again with amoxicillin associated to clavulanic acid for 30 days. Implant removal was recommended after the bone healed. The implants were removed 3 months and a half after the 1st surgery and new bacterial culture was performed, showing the presence of the same microbiological agent. Drains were put in place and more antibiotherapy was implemented. In the third case of infection, the patient had a previous diagnosis of *Malassezia* overgrowth (MOG), bacterial overgrowth (BOG) and chronic ear infections. The patient was presented 22 days after surgery with oedema of the stifle and serosanguineous drainage. An articular punction was performed and bacterial culture and sensitity test was requested. The analysis showed growth of a multi-resistant bacteria, methicillin-resistant *Staphylococcus pseudintermedius* (MRSP). Antibiotherapy had been started with cefalexin and was then changed to a combination of cefalexin with clindamycin. Although, the dog showed improvement, 7 months after surgery a new fistula appeared and the implants were removed.

This same dog rupture the contralateral CrCL less than one month after surgery and a TPLO on the other stifle was performed. Unfortunately, 5 days after surgery the dog presented at the hospital with severe oedema, cutaneous hematoma, serosanguineous discharge and proprioceptive deficit. Compartment syndrome with sciatic compression was suspected. A second intervention was performed and revealed an important sanguineous clot on the medial aspect of the tibia. The surgical site was cleaned, and drains were put in place. Samples for bacterial culture were taken and showed the presence of *Escherichia coli*. Necrotizing fasciitis developed with persistent bleeding and for several days cleaning of the wound and applications of new bandages were performed to try to preserved and recover the limb. At some point, the patient went into shock and an amputation was required (15 days after surgery). The implant was sent for microbial culture and antibiotic sensitivity test, which revealed presence of *Proteus mirarilis*, and the dog was treated with cefalexin and clindamycin.

A single case of implant failure was reported (figure 15). The patient presented a tibial

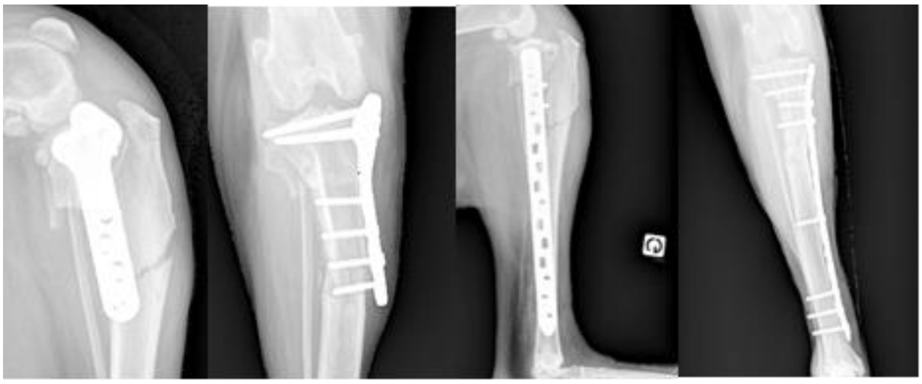


Figure 15. Implant failure at 4 weeks after surgery (A) and stabilization (B). Provided by CHV-Frégis.

and fibular fracture one month after surgery. The histological analysis was in favour of ischemic necrosis. The implant was removed and replaced to stabilize the fracture and 3 months after surgery no complications were found and the bone was still healing.

One case of a seroma with delayed wound healing was reported and classified as a major complication because it needed a second surgical intervention for cleaning of the surgical site and positioning of drains. Bacterial culture was negative. Later, this patient developed systemic signs of infection and an empiric antibiotherapy was instituted, but 11 months after surgery implant removal was necessary due to infection.

Table 4. Major complications following Tibial Plateau Levelling Ostectomy in 38 stifle joints.

Complication	Number of cases	Additional details	Treatment
Infection	3	One methicillin-resistant *Staphylococcus pseudintermedius* (MRSP), another associated with oedema - *Enterobacter cloacae*, and a third one associated with fistula - *Staphylococcus pseudintermedius*	Antibiotherapy, drains and implant removal after bone healed
Implant failure/fracture	1	Tibial and fibular fracture, maybe due to ischemic necrosis	Implant removal and replacement
Compartment Syndrome/Infection	1	Severe oedema, cutaneous hematoma, serosanguineous discharge and proprioceptive deficit. Presence of *E. coli* and *Proteus mirabilis*	Amputation and antibiotherapy
Seroma/delayed wound healing	1	Bacterial culture negative	Drain

4.3 Risk factors analysis

An analysis was performed in order to determine whether preoperative and postoperative factors were associated with the occurrence of major and minor complications.

The age of the dog (Young/Adult) was not significantly associated with the occurrence of complications ($X^2_{(1)}$=0.42, p=0.52), regardless of being major ($X^2_{(1)}$=0.56, p=0.46) or minor ($X^2_{(1)}$=0.01, p=0.92). Gender also did not have an influence in the occurrence of complications ($X^2_{(1)}$=0.10, p=0.76), either for major ($X^2_{(1)}$=2.70, p=0.10) or minor ($X^2_{(1)}$=0.85, p=0.36). There was also no association between the presence of complications and which posterior limb was operated (Right/Left) ($X^2_{(1)}$=0.10, p=0.76), either for major ($X^2_{(1)}$=0.02, p=0.89) or minor complications ($X^2_{(1)}$=0.18, p=0.67). The type of rupture (Total/Partial) was not significantly associated with complications ($X^2_{(1)}$=0.33, p=0.57), major ($X^2_{(1)}$=0.02, p=0.90) or minor ($X^2_{(1)}$=0.25, p=0.62), neither was the presence of meniscal tear at the time of surgery ($X^2_{(1)}$=0.33, p=0.57), regardless of it being a major ($X^2_{(1)}$=0.02, p=0.90), or minor ($X^2_{(1)}$=0.25, p=0.62) complication. The pre-operative degree of lameness did not have an association with the presence of complications either ($X^2_{(1)}$=1.76, p=0.18). The post-operative TPA was not associated with the development of complications ($X^2_{(1)}$=0.12, p=0.72), either major ($X^2_{(1)}$=0.03, p=0.85), or minor ($X^2_{(1)}$=0.25, p=0.61). The diagnosis of bilateral or unilateral rupture at the first evaluation did not have an association with the occurrence of complications ($X^2_{(1)}$=0.18 p=0.65), major ($X^2_{(1)}$=2.72, p=0.099) or minor ($X^2_{(1)}$=0.65, p=0.42). The presence of complications was not significantly associated with experience of the 1st surgeon (Board-certificated surgeon/Resident surgeon) ($X^2_{(1)}$=0.35, p=0.55), for either major ($X^2_{(1)}$=2.21, p=0.14) or minor ($X^2_{(1)}$=3.02, p=0.08) complications.

Curiously, the Size of the implant (<3.5 mm/≥3.5 mm) was significantly associated with the development of complications ($X^2_{(1)}$= 6.55, p=0.01).

IV. DISCUSSION

The aim of this study was to evaluate the short-term complications after TPLO surgery performed at the CHV Frégis. Although, it was a specific population, it was possible to find similarities with other studies on CrCL rupture. Middle-age dogs (mean 5.2 years), most of them sterilized (63.3%) and some breeds that are considered more susceptible to develop this conditions (Witsberger et al. 2008; Taylor-Brown et al. 2015), like American Staffordshire terrier (16.7%), Labrador (6.7%) and Golden retrievers (6.7%), were present in this population. So, this population fits the described by the literature where middle-age dogs, over 4 years old, sterilized and with weigh over 22kg have a higher risk of developing CrCL rupture (Whitehair et al. 1993; Witsberger et al. 2008; Taylor-Brown et al. 2015).

The incidence of bilateral rupture (23.7%) was similar to the incidence described in other studies (Moore and Read 1995; de Bruin et al. 2007; Cabrera et al. 2008; Buote et al. 2009; Grierson et al. 2011; Fuller et al. 2014; Baker and Muir 2017), although the incidence of contralateral rupture after the 1^{st} diagnoses (13.2%) was slightly lower (de Bruin et al. 2007; Cabrera et al. 2008; Buote et al. 2009; Fuller et al. 2014). This may be due to the shorter follow-up time in the present study. Differences in follow-up times among studies may affect the distribution of unilateral *versus* bilateral CrCL rupture, and a prospective study, following dogs to the time of death, would be necessary to differentiate true unilateral rupture from bilateral.

In this retrospective study, TPLO was performed in 30 dogs (38 stifles) and complications associated with the procedure were evaluated. Complications are commonly described as either major or minor, depending on their clinical relevance (Cook et al. 2010). Other studies use similar classification systems, however, the threshold between major and minor complications can be different. For example, in Fitzpatrick and Solano's study (2010) it was the need of a 2^{nd} surgical intervention or lameness for more than 12 weeks. In the present study, the threshold chosen was need for a 2^{nd} surgical intervention. However, this is a subjective judgement, and the comparation between studies may be difficult.

The overall complication rate in this study was 52.6% (20/38), which is higher comparing to the previously published overall complication rates (9.7%-39.1%) following TPLO procedure (Cook et al. 2010; Gatineau et al. 2011), although if the patellar tendinitis had not been considered as a complication, the results would be comparable (39.5%) to the one published by Cook et al. (2010). Some authors may not consider this condition a complication and in studies specifically focusing on the effect of TPLO on the patellar tendon the incidence reported is higher (25.5%) than in other studies (Carey et al. 2005). In this study, patellar tendinitis was considered when the dog showed a patellar tendon thickening and also some degree of lameness, although this may not reflect a true complication and probably overestimates the overall complication rate of this study.

Comparing with extracapsular techniques, the overall complication rate in this study is higher than that found in the literature. The complications rates reported after extracapsular surgery to repair the CrCL rupture ranges from 11.8% to 29.2% (Casale and McCarthy 2009; Cook et al. 2010; Muro and Lanz 2017), varying according to the technique. The lateral fabellotibial suture technique, a modification of an extracapsular technique reported by DeAngelis and Lau, first described in 1970 (DeAngelis and Lau 1970), achieves joint stability by passing heavy, nonabsorbable suture material behind the lateral sesamoid bone of the gastrocnemius muscle and through 1 or 2 bone tunnels made in the tibial tuberosity, trying to mimic the orientation of the CrCL and eliminating cranial drawer motion (Kowaleski et al. 2012; Schulz et al. 2018). Multiple bone anchor systems have been described with different suture materials (Tinga and Kim 2017), however the material can stretch or break, and if that occurs before the healing process is complete, joint stability it is not achieved. In a retrospective study by Casale and McCarthy (2009), the overall complication rate was 17.4% with additional surgery required in 7.2% of the cases, although this rate was lower than the reported for other methods, the authors found an association of higher complication rates with higher body weight and young age. Also, contact with owners was not attempted, so no information about long-term outcome was collected. TightRope CCL®, a minimally invasive procedure in which a multifilament suture, composed of braided ultra-high-molecular-weight polyethylene polyester (FiberTape, Arthrex Inc., Naples, FL), is passed through femoral and tibial bicortical bone tunnels and secured on the medial side of each bone with suture buttons (Kowaleski et al. 2012; Tinga and Kim 2017), has been associated with better outcomes on the stifle stability and kinematics during formation of periarticular fibrosis (Cook et al. 2010). A prospective clinical cohort study of 24 dogs initially reported complications in about 30% of cases, with 17% of cases requiring further treatment (Cook et al. 2010). More recently, the same group reported complications in about 17.8% of 79 dogs treated with TR (Christopher et al. 2013). If Cook et al. (2010) did not find difference between TR and TPLO, in a more recent study TPLO was significantly associated with more major complications than TR, although both techniques were associated with full function outcomes in a subjective assessment of overall long-term functional outcome (Christopher et al. 2013). The Ruby Joint Stabilization System, a bone anchor system with multiple added innovations that uses two titanium alloy bone anchors with ceramic eyelets to secure a multifilament continuous-loop suture to the bone, is associated with substantial improvement of lameness and stifle stability and has the advantage of an early return to mobility allowing, therefore, earlier physical rehabilitation (Muro and Lanz 2017). In a short-term outcome and complications report of 17 clinical cases the overall complication rate was 11.8% with 5.9% of major complications, involving implant failure (Muro and Lanz 2017). Although, the Ruby technique may provide an alternative for owners who are hesitant about the osteotomy procedures, further long-term studies are warranted to evaluate potential fatigue failure, and to compare this technique with other methods of extracapsular stabilisation, as well as osteotomy procedures.

If the findings of this study are compared with those of other osteotomies procedures, the overall complication rate found is higher than the reported for CTWO and comparable with some reports of TTA surgeries.

The CTWO procedure involves a closing-wedge osteotomy performed immediately distal to the tibial crest and stabilised using a medially applied compression plate and screws (Jerram and Walker 2003; Kim et al. 2008; Roe 2017). The lower location of the osteotomy alters the relative position of the tibial crest and can be associated with complications on the stifle extensor mechanism (Schulz et al. 2018), where the stifle becomes relatively hyperextended (Corr 2009). This technique was later replaced by other procedures, that would not alter the length of the tibia and where the osteotomy would not cross the whole shaft of the bone. However, it continues to be a valuable technique for the management of CrCL rupture, especially in young dogs with open tibial physes (Schulz et al. 2018) and in patients with an excessively steep tibial plateau angle (TPA), though it may also be considered if there are associated varus, valgus, or rotational deformities (Kim et al. 2008; Roe 2017). More recently, a modified CTWO was described by Wallace et al. (2011) and proven to be equally effective as the standard CTWO with the advantage that a significantly smaller amount of bone needed to be removed, significantly reducing tibial shortening. This allows greater preservation of bone stock proximally, which may facilitate implant placement, particularly important in cases of excessive TPA, and will reduce the risk of patellar desmitis and fibular fracture (Wallace et al. 2011; Frederick and Cross 2017). In a retrospective study of 300 CTWO the overall complication rate was 31.7% (95/300) and the rate of revision surgery (12.33%) was considerable, with the most important clinical complications being postoperative medial meniscal tears, tibial fractures and implant failures (Kuan et al. 2009). A more recent study reported an overall complication rate of 20.3% with a reoperation rate of 5.4%, although there were no significant differences between CTWO and TPLO complication rates (Oxley et al. 2013).

TTA involves an osteotomy of the non–weight-bearing portion of the tibia and stability is achieved by changing the relative alignment of the patellar tendon to the tibial plateau (Kim et al. 2008; Kowaleski et al. 2012; Schulz et al. 2018), where a frontal plane osteotomy of the tibial crest advances the patellar ligament perpendicular to the tibial plateau, eliminating the cranial tibial thrust. An appropriately sized spacer-cage is implanted at the proximal extent of the osteotomy to secure the tibia (Kim et al. 2008; Boudrieau 2017). Although, TTA is associated with good long-term functional outcomes as a treatment for CrCL rupture, where successful outcomes represent 88.9% (Christopher et al. 2013), this procedure does not fully restore CrCL intact stifle biomechanics (Brown et al. 2015) and it is related to several complications, such as postliminary meniscal tears, tibial tuberosity fractures with or without implant failure, infection, medial patella luxation and tibial fracture (Boudrieau 2017). This procedure is based on the research of Tepic et al. (2002) who states that the total force of the stifle is nearly parallel to the patellar ligament and surgical correction should make the tibial plateau perpendicular to the patellar ligament. The TTA alters the geometry of the tibia so that the patellar tendon angle (PTA), angle between the patellar tendon and the tibial plateau, should be maintained under 90º during weight-bearing, neutralizing the cranial tibiofemoral shear force in a stifle with CrCL rupture (Boudrieau 2017). There is a 2nd generation method evolving, where plates are no longer needed and the major conceptual modification is an incomplete distal osteotomy of the tibial tuberosity, to help stabilize the fixation and neutralization of the distractive force of the quadriceps mechanism that were previously neutralized with a plate (Boudrieau 2017). There are many reports of good to excellent results with overall complication rate from 19% to 59% (Hoffmann et al. 2006; Hirshenson et al. 2012; Wolf et al. 2012; Samoy et al. 2015) and the largest and most recent publication consists of a retrospective study of 501 TTAs reported in 2012 (Wolf et al. 2012) with an overall complication rate of 19%. Although, in a study comparing TTA, TPLO and TR, TTA have been associated with long-term successful functional outcomes but also with higher major complications (Christopher et al. 2013).

At the moment, it is not possible to consider one technique superior to another since none of the different osteotomy surgeries create normal kinematics of the stifle joint. Individual and interbreed differences in morphology and biomechanics may also influence the final outcome after surgery, and some osteotomy procedures may be more suitable than others for certain breeds of dogs or tibial conformations (Kim et al. 2008).

On the other hand, if we compare the rate of complications requiring second surgical intervention, the scenario is slightly different. Although, previously reported rates varied from 3.1% to 6.6% (Fitzpatrick and Solano 2010; Gatineau et al. 2011; Coletti et al. 2014), the incidence of major complication in this study was 15.8%, which is comparable to the major complication rate found in Pacchiana et al. (2003) (13%) and with more recent studies, such as Cook et al. (2010) (17.4%) and Christopher et al. (2013) (18.5%).

In this study, 7.9% of postoperative wound infections were reported. Such a rate is comparable to previously published infection rates after TPLO surgery (3–14%) (Cook et al. 2010; Fitzpatrick and Solano 2010; Frey et al. 2010; Gatineau et al. 2011; Nazarali et al. 2015; Brown et al. 2016) but is higher than previously reported for clean surgery 2.5% to 4.9% (Vasseur et al. 1988; Eugster et al. 2004). The most frequent organism found was *Staphylococcus pseudintermedius* and in all cases the implants had to be removed after the bone healed. The treatment implemented was antibiotherapy based on the antibiotic sensitivity test. There are several risk factors including patient-related factors and operation-related factors, such as duration of surgical scrub, preoperative clipping and skin preparation, duration of surgery and anaesthesia, disruptions in aseptic technique or number of persons in the operating room, that were not taken in consideration given the retrospective nature of this study. These confounding variables were not specifically recorded, which may have potentially affected the results. Also, the immune status (pre-existing infection or colonization with microorganisms) of a specific animal may have influenced the results since this patient had a previous diagnosis of *Malassezia* overgrowth (MOG), bacterial overgrowth (BOG) and chronic ear infections. This animal would a priori have been more likely to develop surgical wound infection since the causative agent is most often endogenous and the patient's skin is a major source of pathogens that cause wound infections. Thus, the patient's clinical background may explain the presence of a methicillin-resistant *Staphylococcus pseudintermedius* (MRSP) in this study.

This same patient also suffered a compartment syndrome associated with infection in the second limb operated (2.6%). Compartment syndrome (CS) is defined as the dysfunction of organs or tissues within a compartment that develops secondary to limited blood supply due to increased pressures within that compartment (Balogh and Butcher 2010). The pathophysiology of CS is an inadequate perfusion and oxygenation of the organs/tissues within the confined space and there are two generally accepted theories: 1) the ischemia-reperfusion syndrome (McMichael and Moore 2004) and 2) the arteriovenous pressure theory (Nielsen and Whelan 2012). Even though these 2 theories are complimentary and not contradictory, the arteriovenous pressure gradient theory is the more widely accepted theory (Balogh and Butcher 2010; Nielsen and Whelan 2012). Once the compartment's perfusion is compromised, a vicious cycle of hypoxia, anaerobic metabolism, oedema, further vasoconstriction, and continued cellular damage takes place. This process is irreversible without intervention, can lead to irreversible damage and in some cases death (Nielsen and Whelan 2012). Most of the understanding of the pathogenesis of CS in dogs is derived from that described in humans, in which this condition is believed to result from increased compartment volume (bleeding, fluid accumulation, or injection), post-ischemic tissue swelling (after vascular surgery), or excessive external pressure (tight external coaptation) (Nielsen and Whelan 2012; Griffon 2016b). In this case, the animal was presented at the hospital 5 days postoperatively with a considerable oedema, a subcutaneous hematoma and proprioceptive deficit. The suspicion of CS with sciatic compression led to an emergency intervention surgery, where an important clot creating an extensive compartment was found. The probable cause considered was compartment syndrome due to postoperative bleeding, maybe related to excessive activity or a coagulation problem, or due to inflammation. There are few case reports of CS in dogs and the true incidence is unknow. Based on the studies in the veterinary literature, dogs diagnosed with CS and treated by emergency fasciotomy respond well to treatment (Griffon 2016b). Despite the quick intervention and all the treatment put in place, the unfortunate development of an infection led the animal to enter into shock, and a radical intervention was necessary which required amputation of the affected limb.

Implant failure/fracture occurred in only one case (2.6%) however, it was a catastrophic failure with fracture of the tibia and fibula that required a new surgical intervention. Implant failure is an infrequent complication, generally with a good prognosis, although some delayed bone healing should be expected. The incidence of this complication was reported at about 2% after TPLO (Priddy et al. 2003; Duerr et al. 2008) and TTA (Wolf et al. 2012), thereby the incidence found in this study is comparable to that reported in the literature. There are several risk factors for this complication such as the use of non-locking screws or failure to obtain bicortical fixation, combining TPLO with cranial wedge osteotomy, excessive postoperative exercise, infection, excessive micromotion at the osteotomy site, concurrent tibial tuberosity or fibular head fractures and delayed bone healing. A wide range of orthopaedic TPLO implants are available in a growing variety of sizes and both locking and non-locking implants can be found. A biomechanical comparison between three different commercial manufacturer's TPLO plates determined that Synthes plates are significantly stiffer than Slocum constructs and that more rigid implants may result in more reliable fixation of potentially unstable metaphyseal osteotomies (Kloc et al. 2009). The use of locking bone screws, compared to conventional bone screws in an identical plate, causes significantly less translational movement of the proximal tibial segment towards the bone plate (Schaefer 2017), this type of fixation having been associated to increased stabilization of TPA during TPLO healing and improved radiographic evidence of osteotomy healing (Conkling et al. 2010). Also, locking plate constructs are associated with lower incidence of infection and lower general complication rate (Kowaleski et al. 2013; Solano et al. 2015). Regardless of the implant selected for TPLO, postoperative exercise restriction until bone union is essential to prevent postoperative complications.

There was one case of seroma/delayed wound healing (2.6%) in this study. This complication could possibly be considered a minor issue despite use of surgery for resolution, therefore it may have overestimated the major complications incidence for short-term complications, even though later this patient had to have the implant removed due to infection. The incidence of seroma after TPLO surgery reported ranges from 0.7% to 13% (Pacchiana et al. 2003; Conkling et al. 2010; Cook et al. 2010; Fitzpatrick and Solano 2010; Garnett and Daye 2014), and it is generally considered a minor complication, not requiring further surgery.

The minor complication incidence found in this study was 36.8%, higher than the incidence reported in other TPLO studies, although as discussed previously, if patellar tendonitis had not been considered, the incidence would be lower and comparable (23.6%) with that found in studies such as Cook et al. (2010) or Garnett and Daye (2014), where the incidence found was 21.7% and 29%, respectively.

In this study, there were 5 cases (13.2%) of delayed wound healing combined with oedema, seroma, discharge or patellar tendonitis. Combined, incisional complications such as inflammation, drainage, swelling and seroma represent the majority of the morbidity associated with TPLO (0.7%-13.3%) and most are self-limiting and do not require further surgical treatment (Griffon 2016a). These incisional complications may be associated with excessive surgical trauma, undermining of skin or excessive animal movement postoperatively.

There was one case of delayed bone healing associated with pivot shift (2.6%). The incidence of delayed bone healing in TPLO reports ranges from 0.3% to 9% (Conkling et al. 2010; Fitzpatrick and Solano 2010; Garnett and Daye 2014) and the risk factors for the occurrence of this complication include systemic illness, compromised vascular supply, unstable implants, extremely rigid fixation, infection and poor postoperative management. The pivot shift is a sudden internal rotation of the tibia with lateralization of the hock, and a sudden lateral change in direction of the stifle joint during weight bearing (Boudrieau 2009; Schulz et al. 2018). The reason for its occurrence is unknown but it is thought to be a result of insufficient correction of tibial torsion or angular deformity (Boudrieau 2009; Gatineau et al. 2011; Schulz et al. 2018). The incidence of pivot shift ranges from 0.3% to 3.2%, although further studies need to be conducted to understand the impact on the biomechanics of the stifle and in the long-term outcome after TPLO surgery. In Gatineau et al. (2011), although the thigh muscular atrophy was not recorded, in some cases, pivot shift disappeared after 4 to 6 months postoperatively with recovery of a satisfactory thigh muscular mass. In this same study, medial meniscectomy was identified as a risk factor for this complication. For this case, an articular punction was performed and bacterial analysis requested to exclude infection as the cause of the delayed bone healing. Two months after the surgery physiotherapy was recommended due to the pivot shift and the delayed bone healing signs, still present.

Patellar tendon thickening can be an accidental radiographic finding, however patellar tendonitis is associated with clinical signs. In this study, patellar tendonitis was considered when patellar tendon thickening was present in the radiographic evaluation and when lameness was also present. Because of the retrospective nature of this study, this incidence may have been overestimated. There were 5 cases (13.2%) of patellar tendonitis and this incidence is comparable to the literature reported, where this complication rate ranges from 0.3% to 25% (Pacchiana et al. 2003; Carey et al. 2005; Stauffer et al. 2006; Conkling et al. 2010; Fitzpatrick and Solano 2010; Garnett and Daye 2014). The treatment includes rest and antiinflamatory drugs, and the outcome is excellent with clinical signs resolved in 1 to 2 months (Griffon 2016a).

There were 3 cases of bone fractures that did not require a second surgery, one tibial tuberosity fracture (2.6%), one patellar osteophyte fracture (2.6%) and one fibular fracture (2.6%). The incidence of tibial tuberosity fracture and fibular fracture found are comparable to the results found in the literature (Bergh et al. 2008; Tuttle and Manley 2009). Patellar fracture or patellar osteophyte fracture is an uncommon complication with an average incidence of 0.4% (Griffon 2016a). In all cases, conservative management was instituted and more time of NSAIDs was required. In the case of patellar osteophyte fracture, physiotherapy was also recommended. Although the recovering time was prolonged, in all cases the final outcome was very good.

Because the aim of this study was the evaluation of short-term complications, the final outcome after TPLO surgery cannot be analysed. No attempt at contact with the owners was performed. However, analysing the degree of lameness, it was possible to observe that at 8 weeks after surgery almost half of the patients had no lameness recorded and only 10.8% of the dogs showed “Mild to Moderate” and “Moderate” lameness. This may evidence some improvement, even in a short-term follow-up, where dogs undergoing TPLO surgery can have a fast return to near-normal function or normal function of the operated limb.

In the risk factor analysis, the complication rates (overall, major and minor) were not associated with age (Young/Adult), gender, operated limb (Right/Left), type of rupture (Total/Partial), presence of meniscal tear, pre-operative degree of lameness, post-operative TPA, diagnosis of bilateral or unilateral rupture, or the experience of the 1st surgeon (Certificated-board surgeon/Resident surgeon), contrarily to that reported in other studies (Pacchiana et al. 2003; Bergh et al. 2008; Fitzpatrick and Solano 2010; Gatineau et al. 2011;

Taylor et al. 2011; Bergh and Peirone 2012), such as in the study of Fitzpatrick and Solano (2010), where complete CrCL rupture was significantly associated with complications. The only variable that was significantly associated with complications was the Size of implant, with medium and larger implants being associated with the presence of complications. Since in this study the records of patient weight were not available, it was not possible to evaluate this variable. Nevertheless, the Size of implant maybe related to body weight/size of the dog and body weight has been reported as a risk factor for complication in fabello-tibial suture surgery and TPLO surgery (Casale and McCarthy 2009; Fitzpatrick and Solano 2010).

Several limitations should be considered when interpreting the results of the present study. One of the major limitations was its retrospective nature, reliance on the completeness of case records and small sample size due to the inclusion criteria that were used which resulted in the exclusion of a large number of dogs. In some cases, owners may have elected treatment elsewhere, since the hospital is a referral centre, some patients may have been followed by their regular clinician and only come back if major complications arose, and this may have overestimated our results. Also, the absence of some parameters in some of the clinical records and the small number of cases analysed did not allow for further analysis of the data such as correlations between events that could have been studied otherwise as, for example the correlation between breeds, body weight, pre-operative TPA and reproductive state with the presence of complications or the risk factors for specific important complications such as infection. Concerning future perspectives, an interesting study would be the evaluation of long-term complications and an owner’s assessment of final outcome of TPLO surgery or a study to obtain objective assessments of limb use with force-plate analyses and kinematic gait evaluations, to analyse the functional outcome of this surgery.

V. CONCLUSION

In the present study, the short-term complications after TPLO surgery were evaluated and risk factors that may influence its occurrence were analysed. Out of 38 TPLO surgeries, the overall complication rate was 56.2%, where 15.8% were major complications and 36.8% minor complications, however these values may be overestimated as a consequence of the reduction in sample size caused by our strict inclusion criteria. Nonetheless, we felt it was important, for interstudy comparability to proceed with the smaller sample size. The more important major complication found was infection and delayed wound healing and patellar tendonitis were the more frequent minor complications. The only risk factor found was the size of implant that maybe related to the body weight of the patient. In conclusion, although TPLO is associated with good to excellent outcomes, generally half of the cases may develop complications, more often minor and especially in the first 4 weeks after surgery.

REFERENCES

Arcand MA, Rhalmi S, Rivard CH. 2000. Quantification of mechanoreceptors in the canine anterior cruciate ligament. Int Orthop. 24(5):272–275. doi:10.1007/s002640000153.

Arnault F, Cauvin E, Viguier E, Kraft E, Sonet J, Carozzo C. 2009. Diagnostic value of ultrasonography to assess stifle lesions in dogs after cranial cruciate ligament rupture: 13 cases. Vet Comp Orthop Traumatol. 22(6):479–485. doi:10.3415/VCOT-08-10-0103.

Atherton MJ, Arthurs G. 2012. Osteosarcoma of the tibia 6 years after tibial plateau leveling osteotomy. J Am Anim Hosp Assoc. 48(3):188–193. doi:10.5326/JAAHA-MS-5730.

Au KK, Gordon-Evans WJ, Dunning D, O'Dell-Anderson KJ, Knap KE, Griffon D, Johnson AL. 2010. Comparison of short- and long-term function and radiographic osteoarthrosis in dogs after postoperative physical rehabilitation and tibial plateau leveling osteotomy or lateral fabellar suture stabilization. Vet Surg. 39(2):173–180. doi:10.1111/j.1532-950X.2009.00628.x.

Baird A, Carter SD, Innes JF, Ollier W, Short A. 2014. Genome-wide association study identifies genomic regions of association for cruciate ligament rupture in Newfoundland dogs. Anim Genet. 45(4):542–549. doi:10.1111/age.12162.

Baird AEG, Carter SD, Innes JF, Ollier WE, Short AD. 2014. Genetic basis of cranial cruciate ligament rupture (CCLR) in dogs. Connect Tissue Res. 55(4):275–281. doi:10.3109/03008207.2014.910199.

Baker LA, Kirkpatrick B, Rosa GJM, Gianola D, Valente B, Sumner JP, Baltzer W, Hao Z, Binversie EE, Volstad N, et al. 2017. Genome-wide association analysis in dogs implicates 99 loci as risk variants for anterior cruciate ligament rupture. PLoS One. 12(4):e0173810. doi:10.1371/journal.pone.0173810.

Baker LA, Muir P. 2017. Epidemiology of Cruciate Ligament Rupture. Adv Canine Cranial Cruciate Ligament.:109–114. doi:https://doi.org/10.1002/9781119261728.ch14. https://doi.org/10.1002/9781119261728.ch14.

Balogh ZJ, Butcher NE. 2010. Compartment syndromes from head to toe. Crit Care Med. 38(9 Suppl):S445-51. doi:10.1097/CCM.0b013e3181ec5d09.

Beal MW, Brown DC, Shofer FS. 2000. The effects of perioperative hypothermia and the duration of anesthesia on postoperative wound infection rate in clean wounds: a retrospective study. Vet Surg. 29(2):123–127. doi:10.1111/j.1532-950x.2000.00123.x.

Beale BS, Hulse DA, Pozzi A, Muir P. 2017. Arthroscopy and Arthrotomy of the Stifle. Adv Canine Cranial Cruciate Ligament.:171–184. doi:https://doi.org/10.1002/9781119261728.ch23.

Belo L, Serrano I, Cunha E, Carneiro C, Tavares L, Miguel Carreira L, Oliveira M. 2018. Skin asepsis protocols as a preventive measure of surgical site infections in dogs: chlorhexidine-alcohol versus povidone-iodine. BMC Vet Res. 14(1):95. doi:10.1186/s12917-018-1368-5.

Bennett D, May C. 1991. Meniscal damage associated with cruciate disease in the dog. J Small Anim Pract. 32(3):111–117. doi:https://doi.org/10.1111/j.1748-5827.1991.tb00524.x. https://doi.org/10.1111/j.1748-5827.1991.tb00524.x.

Bergh MS, Peirone B. 2012. Complications of tibial plateau levelling osteotomy in dogs. Vet Comp Orthop Traumatol. 25(5):349–358. doi:10.3415/VCOT-11-09-0122.

Bergh MS, Rajala-Schultz P, Johnson KA. 2008. Risk factors for tibial tuberosity fracture after tibial plateau leveling osteotomy in dogs. Vet Surg. 37(4):374–382. doi:10.1111/j.1532-950X.2008.00391.x.

Biskup JJ, Conzemius MG. 2017. Intra-Articular Repair for Cranial Cruciate Ligament Rupture in the Dog. Adv Canine Cranial Cruciate Ligament.:201–216. doi:https://doi.org/10.1002/9781119261728.ch26.

Boudrieau RJ. 2009. Tibial plateau leveling osteotomy or tibial tuberosity advancement? Vet Surg. 38(1):1–22. doi:10.1111/j.1532-950X.2008.00439.x.

Boudrieau RJ. 2017. Tibial Tuberosity Advancement. Adv Canine Cranial Cruciate Ligament.:227–242. doi:https://doi.org/10.1002/9781119261728.ch28. https://doi.org/10.1002/9781119261728.ch28.

Boudrieau RJ, McCarthy RJ, Sisson RDJ. 2005. Sarcoma of the proximal portion of the tibia in a dog 5.5 years after tibial plateau leveling osteotomy. J Am Vet Med Assoc. 227(10):1591,1613-1617. doi:10.2460/javma.2005.227.1613.

Boyd DJ, Miller CW, Etue SM, Monteith G. 2007. Radiographic and functional evaluation of dogs at least 1 year after tibial plateau leveling osteotomy. Can Vet J = La Rev Vet Can. 48(4):392–396.

Brown DC, Conzemius MG, Shofer F, Swann H. 1997. Epidemiologic evaluation of postoperative wound infections in dogs and cats. J Am Vet Med Assoc. 210(9):1302–1306.

Brown G, Maddox T, Baglietto Siles MM. 2016. Client-assessed long-term outcome in dogs with surgical site infection following tibial plateau levelling osteotomy. Vet Rec. 179(16):409. doi:10.1136/vr.103688.

Brown NP, Bertocci GE, Marcellin-Little DJ. 2015. Canine Stifle Biomechanics Associated With Tibial Tuberosity Advancement Predicted Using a Computer Model. Vet Surg. 44(7):866–873. doi:10.1111/vsu.12363.

de Bruin T, de Rooster H, van Bree H, Cox E. 2007. Evaluation of anticollagen type I antibody titers in synovial fluid of both stifle joints and the left shoulder joint of dogs with unilateral cranial cruciate disease. Am J Vet Res. 68(3):283–289. doi:10.2460/ajvr.68.3.283.

Budsberg SC. 2017. Medical Therapy for Stifle Osteoarthritis. Adv Canine Cranial Cruciate Ligament.:333–341. doi:https://doi.org/10.1002/9781119261728.ch41. https://doi.org/10.1002/9781119261728.ch41.

Buote N, Fusco J, Radasch R. 2009. Age, tibial plateau angle, sex, and weight as risk factors for contralateral rupture of the cranial cruciate ligament in Labradors. Vet Surg. 38(4):481–489. doi:10.1111/j.1532-950X.2009.00532.x.

Cabrera SY, Owen TJ, Mueller MG, Kass PH. 2008. Comparison of tibial plateau angles in dogs with unilateral versus bilateral cranial cruciate ligament rupture: 150 cases (2000-2006). J Am Vet Med Assoc. 232(6):889–892. doi:10.2460/javma.232.6.889.

Carey K, Aiken SW, DiResta GR, Herr LG, Monette S. 2005. Radiographic and clinical changes of the patellar tendon after tibial plateau leveling osteotomy 94 cases (2000-2003). Vet Comp Orthop Traumatol. 18(4):235–242.

Casale SA, McCarthy RJ. 2009. Complications associated with lateral fabellotibial suture surgery for cranial cruciate ligament injury in dogs: 363 cases (1997-2005). J Am Vet Med Assoc. 234(2):229–235. doi:10.2460/javma.234.2.229.

Case JB, Hulse D, Kerwin SC, Peycke LE. 2008. Meniscal injury following initial cranial cruciate ligament stabilization surgery in 26 dogs (29 stifles). Vet Comp Orthop Traumatol. 21(4):365–367. doi:10.3415/vcot-07-07-0070.

Christopher SA, Beetem J, Cook JL. 2013. Comparison of long-term outcomes associated with three surgical techniques for treatment of cranial cruciate ligament disease in dogs. Vet Surg. 42(3):329–334. doi:10.1111/j.1532-950X.2013.12001.x.

Coletti TJ, Anderson M, Gorse MJ, Madsen R. 2014. Complications associated with tibial plateau leveling osteotomy: a retrospective of 1519 procedures. Can Vet J = La Rev Vet Can. 55(3):249–254. https://pubmed.ncbi.nlm.nih.gov/24587508.

Collins JE, Degner DA, Hauptman JG, DeCamp CE. 2014. Benefits of pre- and intraoperative planning for tibial plateau leveling osteotomy. Vet Surg. 43(2):142–149. doi:10.1111/j.1532-950X.2013.12093.x.

Comerford E, Forster K, Gorton K, Maddox T. 2013. Management of cranial cruciate ligament rupture in small dogs: a questionnaire study. Vet Comp Orthop Traumatol. 26(6):493–497. doi:10.3415/VCOT-12-06-0070.

Conkling AL, Fagin B, Daye RM. 2010. Comparison of tibial plateau angle changes after tibial plateau leveling osteotomy fixation with conventional or locking screw technology. Vet Surg. 39(4):475–481. doi:10.1111/j.1532-950X.2010.00656.x.

Conzemius MG, Evans RB, Besancon MF, Gordon WJ, Horstman CL, Hoefle WD, Nieves MA, Wagner SD. 2005. Effect of surgical technique on limb function after surgery for rupture of the cranial cruciate ligament in dogs. J Am Vet Med Assoc. 226(2):232–236. doi:10.2460/javma.2005.226.232.

Cook CR. 2016. Ultrasound Imaging of the Musculoskeletal System. Vet Clin North Am Small Anim Pract. 46(3):355–71, v. doi:10.1016/j.cvsm.2015.12.001.

Cook CR. 2017. Stifle Ultrasonography. Adv Canine Cranial Cruciate Ligament.:135–140. doi:https://doi.org/10.1002/9781119261728.ch19.

Cook JL, Luther JK, Beetem J, Karnes J, Cook CR. 2010. Clinical comparison of a novel extracapsular stabilization procedure and tibial plateau leveling osteotomy for treatment of cranial cruciate ligament deficiency in dogs. Vet Surg. 39(3):315–323. doi:10.1111/j.1532-950X.2010.00658.x.

Corr S. 2009. Decision making in the management cruciate disease in dogs. In Pract. 31(4):164–171. doi:https://doi.org/10.1136/inpract.31.4.164. https://doi.org/10.1136/inpract.31.4.164.

DeAngelis M, Lau RE. 1970. A lateral retinacular imbrication technique for the surgical correction of anterior cruciate ligament rupture in the dog. J Am Vet Med Assoc. 157(1):79–84.

Denny HR, Butterworth SJ. 2000. The Stifle. A Guid to Canine Feline Orthop Surg.:512–553. doi:https://doi.org/10.1002/9780470699027.ch42.

Dillon DE, Gordon-Evans WJ, Griffon DJ, Knap KM, Bubb CL, Evans RB. 2014. Risk factors and diagnostic accuracy of clinical findings for meniscal disease in dogs with cranial cruciate ligament disease. Vet Surg. 43(4):446–450. doi:10.1111/j.1532-950X.2014.12103.x.

Doom M, de Bruin T, de Rooster H, van Bree H, Cox E. 2008. Immunopathological mechanisms in dogs with rupture of the cranial cruciate ligament. Vet Immunol Immunopathol. 125(1–2):143–161. doi:10.1016/j.vetimm.2008.05.023.

Drygas KA, Pozzi A, Goring RL, Horodyski M, Lewis DD. 2010. Effect of tibial plateau leveling osteotomy on patellar tendon angle: a radiographic cadaveric study. Vet Surg. 39(4):418–424. doi:10.1111/j.1532-950X.2010.00665.x.

Duerr FM, Duncan CG, Savicky RS, Park RD, Egger EL, Palmer RH. 2007. Risk factors for excessive tibial plateau angle in large-breed dogs with cranial cruciate ligament disease. J Am Vet Med Assoc. 231(11):1688–1691. doi:10.2460/javma.231.11.1688.

Duerr FM, Duncan CG, Savicky RS, Park RD, Egger EL, Palmer RH. 2008. Comparison of surgical treatment options for cranial cruciate ligament disease in large-breed dogs with excessive tibial plateau angle. Vet Surg. 37(1):49–62. doi:10.1111/j.1532-950X.2007.00348.x.

Duerr FM, Martin KW, Rishniw M, Palmer RH, Selmic LE. 2014. Treatment of canine cranial cruciate ligament disease. A survey of ACVS Diplomates and primary care veterinarians. Vet Comp Orthop Traumatol. 27(6):478–483. doi:10.3415/VCOT-14-03-0047.

Duval JM, Budsberg SC, Flo GL, Sammarco JL. 1999. Breed, sex, and body weight as risk factors for rupture of the cranial cruciate ligament in young dogs. J Am Vet Med Assoc. 215(6):811–814.

Dyce K., Sack WO, Wensing CJG. 2010. The Hindlimb of the dog and Cat. In: Textbook of veterinary anatomy. Fifth edit. St. Louis, Missouri: Elsevier. p. pp.490-500.

Eugster S, Schawalder P, Gaschen F, Boerlin P. 2004. A prospective study of postoperative surgical site infections in dogs and cats. Vet Surg. 33(5):542–550. doi:10.1111/j.1532-950X.2004.04076.x.

Evans HE, de Lahunta A. 2013. Arthrology. In: Miller's Anatomy of the Dog. 4th ed. St. Louis, Missouri: Elsevier Saunders. p. 175–183.

Fitzpatrick N, Solano MA. 2010. Predictive variables for complications after TPLO with stifle inspection by arthrotomy in 1000 consecutive dogs. Vet Surg. 39(4):460–474. doi:10.1111/j.1532-950X.2010.00663.x.

Frederick SW, Cross AR. 2017. Modified cranial closing wedge osteotomy for treatment of cranial cruciate ligament insufficiency in dogs with excessive tibial plateau angles: Technique and complications in 19 cases. Vet Surg. 46(3):403–411. doi:10.1111/vsu.12614.

Frey TN, Hoelzler MG, Scavelli TD, Fulcher RP, Bastian RP. 2010. Risk factors for surgical site infection-inflammation in dogs undergoing surgery for rupture of the cranial cruciate ligament: 902 cases (2005-2006). J Am Vet Med Assoc. 236(1):88–94. doi:10.2460/javma.236.1.88.

Fuller MC, Hayashi K, Bruecker KA, Holsworth IG, Sutton JS, Kass PH, Kantrowitz BJ, Kapatkin AS. 2014. Evaluation of the radiographic infrapatellar fat pad sign of the contralateral stifle joint as a risk factor for subsequent contralateral cranial cruciate ligament rupture in dogs with unilateral rupture: 96 cases (2006-2007). J Am Vet Med Assoc. 244(3):328–338. doi:10.2460/javma.244.3.328.

Galindo-Zamora V, Dziallas P, Ludwig DC, Nolte I, Wefstaedt P. 2013. Diagnostic accuracy of a short-duration 3 Tesla magnetic resonance protocol for diagnosing stifle joint lesions in dogs with non-traumatic cranial cruciate ligament rupture. BMC Vet Res. 9:40. doi:10.1186/1746-6148-9-40.

Galloway RH, Lester SJ. 1995. Histopathological evaluation of canine stifle joint synovial membrane collected at the time of repair of cranial cruciate ligament rupture. J Am Anim Hosp Assoc. 31(4):289–294. doi:10.5326/15473317-31-4-289.

Garnett SD, Daye RM. 2014. Short-term complications associated with TPLO in dogs using 2.0 and 2.7 mm plates. J Am Anim Hosp Assoc. 50(6):396–404. doi:10.5326/JAAHA-MS-6074.

Gatineau M, Dupuis J, Planté J, Moreau M. 2011. Retrospective study of 476 tibial plateau levelling osteotomy procedures. Rate of subsequent “pivot shift”, meniscal tear and other complications. Vet Comp Orthop Traumatol. 24(5):333–341. doi:10.3415/VCOT-10-07-0109.

Gnudi G, Bertoni G. 2001. Echographic examination of the stifle joint affected by cranial cruciate ligament rupture in the dog. Vet Radiol ultrasound Off J Am Coll Vet Radiol Int Vet Radiol Assoc. 42(3):266–270. doi:10.1111/j.1740-8261.2001.tb00938.x.

Gordon WJ, Conzemius MG, Riedesel E, Besancon MF, Evans R, Wilke V, Ritter MJ. 2003. The relationship between limb function and radiographic osteoarthrosis in dogs with stifle osteoarthrosis. Vet Surg. 32(5):451–454. doi:10.1053/jvet.2003.50051.

Grierson J, Asher L, Grainger K. 2011. An investigation into risk factors for bilateral canine cruciate ligament rupture. Vet Comp Orthop Traumatol. 24(3):192–196. doi:10.3415/VCOT-10-03-0030.

Griffon D. 2016a. Complications associated with cranial cruciate ligament repair. Complicat Small Anim Surg.:867–888. doi:https://doi.org/10.1002/9781119421344.ch117.

Griffon D. 2016b. Complications Associated With External Coaptation. Complicat Small Anim Surg.:110–117. doi:https://doi.org/10.1002/9781119421344.ch16. https://doi.org/10.1002/9781119421344.ch16.

Griffon DJ. 2010. Secondary bone healing. In: Bojrab MJ, Monnet E, editors. Mechanisms of disease in small animal surgery. 3rd ed. Jackson, Wyo.: Teton NewMedia.

Han S, Cheon H, Cho H, Kim J, Kang JH, Yang MP, Lee Y, Lee H, Chang D. 2008. Evaluation of partial cranial cruciate ligament rupture with positive contrast computed tomographic arthrography in dogs. J Vet Sci. 9(4):395–400. doi:10.4142/jvs.2008.9.4.395.

Hans EC, Barnhart MD, Kennedy SC, Naber SJ. 2017. Comparison of complications following tibial tuberosity advancement and tibial plateau levelling osteotomy in very large and giant dogs 50 kg or more in body weight. Vet Comp Orthop Traumatol. 30(4):299–305. doi:10.3415/VCOT-16-07-0106.

Harasen GLG, Simko E. 2008. Histiocytic sarcoma of the stifle in a dog with cranial cruciate ligament failure and TPLO treatment. Vet Comp Orthop Traumatol. 21(4):375–377. doi:10.3415/vcot-07-05-0054.

Hayashi K. 2017. Histology of Cruciate Ligament Rupture. Adv Canine Cranial Cruciate Ligament.:47–55. doi:https://doi.org/10.1002/9781119261728.ch6.

Hayashi K, Frank JD, Dubinsky C, Zhengling H, Markel MD, Manley PA, Muir P. 2003. Histologic changes in ruptured canine cranial cruciate ligament. Vet Surg. 32(3):269–277. doi:10.1053/jvet.2003.50023.

Hayda RA, Brighton CT, Esterhai JLJ. 1998. Pathophysiology of delayed healing. Clin Orthop Relat Res.(355 Suppl):S31-40. doi:10.1097/00003086-199810001-00005.

Haynes KH, Biskup J, Freeman A, Conzemius MG. 2015. Effect of tibial plateau angle on cranial cruciate ligament strain: an ex vivo study in the dog. Vet Surg. 44(1):46–49.

doi:10.1111/j.1532-950X.2014.12219.x.

Henderson R, Milton J. 1978. The tibial compression mechanism: A diagnostic aid in stifle injuries. J Am Anim Hosp Assoc. 14:474–479.

Hirshenson MS, Krotscheck U, Thompson MS, Knapp-Hoch HM, Jay-Silva AR, McConkey M, Bliss SP, Todhunter R, Mohammed HO. 2012. Evaluation of complications and short-term outcome after unilateral or single-session bilateral tibial tuberosity advancement for cranial cruciate rupture in dogs. Vet Comp Orthop Traumatol. 25(5):402–409. doi:10.3415/VCOT-11-12-0175.

Hoffer MJ, Griffon DJ, Schaeffer DJ, Johnson AL, Thomas MW. 2008. Clinical applications of demineralized bone matrix: a retrospective and case-matched study of seventy-five dogs. Vet Surg. 37(7):639–647. doi:10.1111/j.1532-950X.2008.00430.x.

Hoffmann DE, Miller JM, Ober CP, Lanz OI, Martin RA, Shires PK. 2006. Tibial tuberosity advancement in 65 canine stifles. Vet Comp Orthop Traumatol. 19(4):219–227.

Hurley CR, Hammer DL, Shott S. 2007. Progression of radiographic evidence of osteoarthritis following tibial plateau leveling osteotomy in dogs with cranial cruciate ligament rupture: 295 cases (2001-2005). J Am Vet Med Assoc. 230(11):1674–1679. doi:10.2460/javma.230.11.1674.

Inauen R, Koch D, Bass M, Haessig M. 2009. Tibial tuberosity conformation as a risk factor for cranial cruciate ligament rupture in the dog. Vet Comp Orthop Traumatol. 22(1):16–20.

Jerram RM, Walker AM. 2003. Cranial cruciate ligament injury in the dog: pathophysiology, diagnosis and treatment. N Z Vet J. 51(4):149–158. doi:10.1080/00480169.2003.36357.

Johnson A. 2016. Delayed Union. Complicat Small Anim Surg.:665–668. doi:https://doi.org/10.1002/9781119421344.ch98.

Kim SE. 2017. Stress Imaging of the Stifle. Adv Canine Cranial Cruciate Ligament.:127–133. doi:https://doi.org/10.1002/9781119261728.ch18.

Kim SE, Jones SC, Lewis DD, Banks SA, Conrad BP, Tremolada G, Abbasi AZ, Coggeshall JD, Pozzi A. 2015. In-vivo three-dimensional knee kinematics during daily activities in dogs. J Orthop Res Off Publ Orthop Res Soc. 33(11):1603–1610. doi:10.1002/jor.22927.

Kim SE, Pozzi A, Kowaleski MP, Lewis DD. 2008. Tibial osteotomies for cranial cruciate ligament insufficiency in dogs. Vet Surg. 37(2):111–125. doi:10.1111/j.1532-950X.2007.00361.x.

Kloc PA 2nd, Kowaleski MP, Litsky AS, Brown NO, Johnson KA. 2009. Biomechanical comparison of two alternative tibial plateau leveling osteotomy plates with the original standard in an axially loaded gap model: an in vitro study. Vet Surg. 38(1):40–48. doi:10.1111/j.1532-950X.2008.00464.x.

König H-E, Liebich H, Pérez W. 2020. Veterinary Anatomy of Domestic Animals.

Kowaleski MP, Boudrieau RJ, Beale BS, Piras A, Hulse D, Johnson KA. 2013. Radiographic outcome and complications of tibial plateau leveling osteotomy stabilized with an anatomically contoured locking bone plate. Vet Surg. 42(7):847–852. doi:10.1111/j.1532-950X.2013.12048.x.

Kowaleski MP, Boudrieau RJ, Pozzi A. 2012. Stifle Joint. In: Veterinary surgery : small animal.

St. Louis, Mo.: Elsevier. p. 906–970.

Kramer M, Stengel H, Gerwing M, Schimke E, Sheppard C. 1999. SONOGRAPHY OF THE CANINE STIFLE. Vet Radiol Ultrasound. 40(3):282–293. doi:https://doi.org/10.1111/j.1740-8261.1999.tb00363.x.

Kuan S, Smith B, Black A. 2009. Tibial wedge ostectomy: complications of 300 surgical procedures. Aust Vet J. 87(11):438–444. doi:10.1111/j.1751-0813.2009.00482.x.

Laitinen-Vapaavuori O. 2016. Surgical Wound Infections. Complicat Small Anim Surg.:1–7. doi:https://doi.org/10.1002/9781119421344.ch1.

Lampman TJ, Lund E, Lipowitz AJ. 2003. Cranial cruciate disease: Current status of diagnosis, surgery, and risk for disease. Vet Comp Orthop Traumatol. 16:122–126. doi:10.1055/s-0038-1632767.

Lewis BA, Allen DA, Henrikson TD, Lehenbauer TW. 2008. Computed tomographic evaluation of the canine intercondylar notch in normal and cruciate deficient stifles. Vet Comp Orthop Traumatol. 21(2):119–124. doi:10.3415/vcot-07-04-0032.

Lineberger JA, Allen DA, Wilson ER, Tobias TA, Shaiken LG, Shiroma JT, Biller DS, Lehenbauer TW. 2005. Comparison of radiographic arthritic changes associated with two variations of tibial plateau leveling osteotomy. Vet Comp Orthop Traumatol. 18(1):13–17.

Lopez MJ, Hagquist W, Jeffrey SL, Gilbertson S, Markel MD. 2004. Instrumented measurement of in vivo anterior-posterior translation in the canine knee to assess anterior cruciate integrity. J Orthop Res Off Publ Orthop Res Soc. 22(5):949–954. doi:10.1016/j.orthres.2003.10.017.

Luther JK, Cook CR, Cook JL. 2009. Meniscal release in cruciate ligament intact stifles causes lameness and medial compartment cartilage pathology in dogs 12 weeks postoperatively. Vet Surg. 38(4):520–529. doi:10.1111/j.1532-950X.2009.00520.x.

Mahn MM, Cook JL, Cook CR, Balke MT. 2005. Arthroscopic verification of ultrasonographic diagnosis of meniscal pathology in dogs. Vet Surg. 34(4):318–323. doi:10.1111/j.1532-950X.2005.00049.x.

Mangram AJ, Horan TC, Pearson ML, Silver LC, Jarvis WR. 1999. Guideline for Prevention of Surgical Site Infection, 1999. Centers for Disease Control and Prevention (CDC) Hospital Infection Control Practices Advisory Committee. Am J Infect Control. 27(2):97–132; quiz 133–4; discussion 96.

McMichael M, Moore RM. 2004. Ischemia–reperfusion injury pathophysiology, part I. J Vet Emerg Crit Care. 14(4):231–241. doi:https://doi.org/10.1111/j.1476-4431.2004.04004.x. https://doi.org/10.1111/j.1476-4431.2004.04004.x.

Mescher A, Junqueira LCU. 2016. Junqueira’s Basic Histology Text & Atlas (14th ed.).

Moore KW, Read RA. 1995. Cranial cruciate ligament rupture in the dog—a retrospective study comparing surgical techniques. Aust Vet J. 72(8):281–285. doi:https://doi.org/10.1111/j.1751-0813.1995.tb03555.x.

Morris E, Lipowitz AJ. 2001. Comparison of tibial plateau angles in dogs with and without cranial cruciate ligament injuries. J Am Vet Med Assoc. 218(3):363–366. doi:10.2460/javma.2001.218.363.

Mossman H, von Pfeil DJF, Nicholson M, Phelps H, Morris E, Bradley R, Taylor J, Langenbach A. 2015. Accuracy of three pre- and intra-operative measurement techniques for osteotomy positioning in the tibial plateau levelling procedure. Vet Comp Orthop Traumatol. 28(4):250–255. doi:10.3415/VCOT-14-12-0188.

Mostafa AA, Griffon DJ, Thomas MW, Constable PD. 2009. Morphometric characteristics of the pelvic limbs of Labrador Retrievers with and without cranial cruciate ligament deficiency. Am J Vet Res. 70(4):498–507. doi:10.2460/ajvr.70.4.498.

Moucha CS, Clyburn T, Evans RP, Prokuski L. 2011. Modifiable Risk Factors for Surgical Site Infection. JBJS. 93(4). https://journals.lww.com/jbjsjournal/Fulltext/2011/02160/Modifiable_Risk_Factors_for_Surgical_Site.13.aspx.

Muir P. 1997. Physical examination of lame dogs. Compend Cont Ed Pr Vet. 19:1149–1161.

Muir P. 2017. History and Clinical Signs of Cruciate Ligament Rupture. Adv Canine Cranial Cruciate Ligament.:115–118. doi:https://doi.org/10.1002/9781119261728.ch15.

Muro NM, Lanz OI. 2017. Use of a novel extracapsular bone anchor system for stabilisation of cranial cruciate ligament insufficiency. J Small Anim Pract. 58(5):284–292. doi:10.1111/jsap.12669.

Nazarali A, Singh A, Moens NMM, Gatineau M, Sereda C, Fowler D, Kim SE, Kisiel A, Reynolds D, Ringwood BR, et al. 2015. Association between methicillin-resistant Staphylococcus pseudintermedius carriage and the development of surgical site infections following tibial plateau leveling osteotomy in dogs. J Am Vet Med Assoc. 247(8):909–916. doi:10.2460/javma.247.8.909.

Nazarali A, Singh A, Weese JS. 2014. Perioperative administration of antimicrobials during tibial plateau leveling osteotomy. Vet Surg. 43(8):966–971. doi:10.1111/j.1532-950X.2014.12269.x.

Nicholson M, Beal M, Shofer F, Brown DC. 2002. Epidemiologic evaluation of postoperative wound infection in clean-contaminated wounds: A retrospective study of 239 dogs and cats. Vet Surg. 31(6):577–581. doi:10.1053/jvet.2002.34661.

Nielen AL, Knol BW, van Hagen MA, van der Gaag I. 2003. [Genetic and epidemiological investigation of a birth cohort of boxers]. Tijdschr Diergeneeskd. 128(19):586–590.

Nielsen LK, Whelan M. 2012. Compartment syndrome: pathophysiology, clinical presentations, treatment, and prevention in human and veterinary medicine. J Vet Emerg Crit Care. 22(3):291–302. doi:https://doi.org/10.1111/j.1476-4431.2012.00750.x. https://doi.org/10.1111/j.1476-4431.2012.00750.x.

Noorani A, Rabey N, Walsh SR, Davies RJ. 2010. Systematic review and meta-analysis of preoperative antisepsis with chlorhexidine versus povidone-iodine in clean-contaminated surgery. Br J Surg. 97(11):1614–1620. doi:10.1002/bjs.7214.

Ochi H, Hara Y, Asou Y, Harada Y, Nezu Y, Yogo T, Shinomiya K, Tagawa M. 2011. Effects of long-term administration of carprofen on healing of a tibial osteotomy in dogs. Am J Vet Res. 72(5):634–641. doi:10.2460/ajvr.72.5.634.

Oxley B, Gemmill T, Renwick A, Clements D, McKee W. 2013. Comparison of Complication Rates and Clinical Outcome Between Tibial Plateau Leveling Osteotomy and a Modified Cranial Closing Wedge Osteotomy for Treatment of Cranial Cruciate Ligament Disease in Dogs. Vet Surg. 42. doi:10.1111/j.1532-950X.2013.12033.x.

Pacchiana PD, Morris E, Gillings SL, Jessen CR, Lipowitz AJ. 2003. Surgical and postoperative complications associated with tibial plateau leveling osteotomy in dogs with cranial cruciate ligament rupture: 397 cases (1998-2001). J Am Vet Med Assoc.

222(2):184–193. doi:10.2460/javma.2003.222.184.

Pluhar GE. 2016. Fracture-Associated Sarcoma. Complicat Small Anim Surg.:697–701. doi:https://doi.org/10.1002/9781119421344.ch104.

Pozzi A, Dunbar NJ, Kim SE. 2013. Effect of tibial plateau leveling osteotomy on patellofemoral alignment: a study using canine cadavers. Vet J. 198(1):98–102. doi:10.1016/j.tvjl.2013.06.029.

Pozzi Antonio, Hildreth BE 3rd, Rajala-Schultz PJ. 2008. Comparison of arthroscopy and arthrotomy for diagnosis of medial meniscal pathology: an ex vivo study. Vet Surg. 37(8):749–755. doi:10.1111/j.1532-950X.2008.00442.x.

Pozzi A, Kim SE, Tinga S. 2017. Biomechanics of the Cranial Cruciate Ligament-Deficient Stifle Treated by Tibial Osteotomies. Adv Canine Cranial Cruciate Ligament.:271–277. doi:https://doi.org/10.1002/9781119261728.ch32.

Pozzi A, Litsky AS, Field J, Apelt D, Meadows C, Johnson KA. 2008. Pressure distributions on the medial tibial plateau after medial meniscal surgery and tibial plateau levelling osteotomy in dogs. Vet Comp Orthop Traumatol. 21(1):8–14. doi:10.3415/VCOT-06-12-0099.

Priddy NH 2nd, Tomlinson JL, Dodam JR, Hornbostel JE. 2003. Complications with and owner assessment of the outcome of tibial plateau leveling osteotomy for treatment of cranial cruciate ligament rupture in dogs: 193 cases (1997-2001). J Am Vet Med Assoc. 222(12):1726–1732. doi:10.2460/javma.2003.222.1726.

Ragetly CA, Evans R, Mostafa AA, Griffon DJ. 2011. Multivariate analysis of morphometric characteristics to evaluate risk factors for cranial cruciate ligament deficiency in Labrador retrievers. Vet Surg. 40(3):327–333. doi:10.1111/j.1532-950X.2010.00787.x.

Ragetly G, Griffon D. 2016. Degenerative Joint Disease. Complicat Small Anim Surg.:126–134. doi:https://doi.org/10.1002/9781119421344.ch18.

Ralphs SC, Whitney WO. 2002. Arthroscopic evaluation of menisci in dogs with cranial cruciate ligament injuries: 100 cases (1999-2000). J Am Vet Med Assoc. 221(11):1601–1604. doi:10.2460/javma.2002.221.1601.

Rayward RM, Thomson DG, Davies J V, Innes JF, Whitelock RG. 2004. Progression of osteoarthritis following TPLO surgery: a prospective radiographic study of 40 dogs. J Small Anim Pract. 45(2):92–97. doi:10.1111/j.1748-5827.2004.tb00209.x.

Reif U, Hulse DA, Hauptman JG. 2002. Effect of tibial plateau leveling on stability of the canine cranial cruciate-deficient stifle joint: an in vitro study. Vet Surg. 31(2):147–154. doi:10.1053/jvet.2002.31041.

Reif U, Probst CW. 2003. Comparison of tibial plateau angles in normal and cranial cruciate deficient stifles of Labrador retrievers. Vet Surg. 32(4):385–389. doi:10.1053/jvet.2003.50047.

Ritzo ME, Ritzo BA, Siddens AD, Summerlott S, Cook JL. 2014. Incidence and type of meniscal injury and associated long-term clinical outcomes in dogs treated surgically for cranial cruciate ligament disease. Vet Surg. 43(8):952–958. doi:10.1111/j.1532-950X.2014.12220.x.

Roe SC. 2017. Closing Cranial Wedge Ostectomy and Triple Tibial Osteotomy. Adv Canine Cranial Cruciate Ligament.:243–252. doi:https://doi.org/10.1002/9781119261728.ch29.

de Rooster H, Van Ryssen B, van Bree H. 1998. Diagnosis of cranial cruciate ligament injury in dogs by tibial compression radiography. Vet Rec. 142(14):366–368. doi:10.1136/vr.142.14.366.

Samii VF, Dyce J. 2004. COMPUTED TOMOGRAPHIC ARTHROGRAPHY OF THE NORMAL CANINE STIFLE. Vet Radiol Ultrasound. 45(5):402–406. doi:https://doi.org/10.1111/j.1740-8261.2004.04072.x.

Samii VF, Dyce J, Pozzi A, Drost WT, Mattoon JS, Green EM, Kowaleski MP, Lehman AM. 2009. Computed tomographic arthrography of the stifle for detection of cranial and caudal cruciate ligament and meniscal tears in dogs. Vet Radiol ultrasound Off J Am Coll Vet Radiol Int Vet Radiol Assoc. 50(2):144–150. doi:10.1111/j.1740-8261.2009.01507.x.

Samoy Y, Verhoeven G, Bosmans T, Van der Vekens E, de Bakker E, Verleyen P, Van Ryssen B. 2015. TTA Rapid: Description of the Technique and Short Term Clinical Trial Results of the First 50 Cases. Vet Surg. 44(4):474–484. doi:10.1111/j.1532-950X.2014.12298.x.

Sartor AJ, Ryan SD, Sellmeyer T, Withrow SJ, Selmic LE. 2014. Bi-institutional retrospective cohort study evaluating the incidence of osteosarcoma following tibial plateau levelling osteotomy (2000-2009). Vet Comp Orthop Traumatol. 27(5):339–345. doi:10.3415/VCOT-14-01-0006.

Sathya S, Gilbert P, Sharma A, Hendrick S. 2014. Effect of tibial plateau levelling osteotomy on patellar tendon angle: a prospective clinical study. Vet Comp Orthop Traumatol. 27(5):346–350. doi:10.3415/VCOT-14-01-0013.

Schaefer SL. 2017. Tibial Plateau Leveling Osteotomy. Adv Canine Cranial Cruciate Ligament.:217–226. doi:https://doi.org/10.1002/9781119261728.ch27.

Schulz K, Hayashi K, Fossum T. 2018. Diseases of the Joints. In: Small animal surgery. London: Mosby International Ltd. p. 1134–1279.

Scrivani P V. 2017. Magnetic Resonance Imaging of the Stifle. Adv Canine Cranial Cruciate Ligament.:155–163. doi:https://doi.org/10.1002/9781119261728.ch21.

Selmic LE, Ryan SD, Boston SE, Liptak JM, Culp WTN, Sartor AJ, Prpich CY, Withrow SJ. 2014. Osteosarcoma following tibial plateau leveling osteotomy in dogs: 29 cases (1997-2011). J Am Vet Med Assoc. 244(9):1053–1059. doi:10.2460/javma.244.9.1053.

Selmic LE, Ryan SD, Ruple A, Pass WE, Withrow SJ. 2018. Association of tibial plateau leveling osteotomy with proximal tibial osteosarcoma in dogs. J Am Vet Med Assoc. 253(6):752–756. doi:10.2460/javma.253.6.752.

Shahar R, Milgram J. 2006. Biomechanics of tibial plateau leveling of the canine cruciate-deficient stifle joint: a theoretical model. Vet Surg. 35(2):144–149. doi:10.1111/j.1532-950X.2006.00125.x.

Slocum B, Slocum TD. 1993. Tibial plateau leveling osteotomy for repair of cranial cruciate ligament rupture in the canine. Vet Clin North Am Small Anim Pract. 23(4):777–795. doi:10.1016/s0195-5616(93)50082-7.

Solano MA, Danielski A, Kovach K, Fitzpatrick N, Farrell M. 2015. Locking plate and screw fixation after tibial plateau leveling osteotomy reduces postoperative infection rate in dogs over 50 kg. Vet Surg. 44(1):59–64. doi:10.1111/j.1532-950X.2014.12212.x.

Solomonow M, Baratta R, Zhou BH, Shoji H, Bose W, Beck C, D'Ambrosia R. 1987. The synergistic action of the anterior cruciate ligament and thigh muscles in maintaining joint stability. Am J Sports Med. 15(3):207–213. doi:10.1177/036354658701500302.

Sprecher CM, Milz S, Suter T, Keating JH, McCarthy RJ, Gueorguiev B, Boudrieau RJ. 2018. Retrospective analysis of corrosion and ion release from retrieved cast stainless steel tibia plateau leveling osteotomy plates in dogs with and without peri-implant osteosarcoma. Am J Vet Res. 79(9):970–979. doi:10.2460/ajvr.79.9.970.

Stauffer K, Tuttle T, Elkins AD, Wehrenberg A, Character B. 2006. Complications Associated With 696 Tibial Plateau Leveling Osteotomies (2001–2003). J Am Anim Hosp Assoc. 42:44–50. doi:10.5326/0420044.

Taylor-Brown FE, Meeson RL, Brodbelt DC, Church DB, McGreevy PD, Thomson PC, O'Neill DG. 2015. Epidemiology of Cranial Cruciate Ligament Disease Diagnosis in Dogs Attending Primary-Care Veterinary Practices in England. Vet Surg. 44(6):777–783. doi:10.1111/vsu.12349.

Taylor J, Langenbach A, Marcellin-Little DJ. 2011. Risk factors for fibular fracture after TPLO. Vet Surg. 40(6):687–693. doi:10.1111/j.1532-950X.2011.00844.x.

Tepic S, Damur DM, Montavon P. 2002. Biomechanics of the stifle joint. In: 1st World Orthopedic Veterinary Congress. Munich,Germany. p. 189–190.

Thieman KM, Pozzi A, Ling H-Y, Lewis DD, Horodyski M. 2009. Contact mechanics of simulated meniscal tears in cadaveric canine stifles. Vet Surg. 38(7):803–810. doi:10.1111/j.1532-950X.2009.00571.x.

Thieman KM, Tomlinson JL, Fox DB, Cook C, Cook JL. 2006. Effect of meniscal release on rate of subsequent meniscal tears and owner-assessed outcome in dogs with cruciate disease treated with tibial plateau leveling osteotomy. Vet Surg. 35(8):705–710. doi:10.1111/j.1532-950X.2006.00214.x.

Tinga S, Kim SE. 2017. Extracapsular Stabilization. Adv Canine Cranial Cruciate Ligament.:189–199. doi:https://doi.org/10.1002/9781119261728.ch25.

Tivers MS, Commerford EJ, Owen MR. 2009. Does a fabella-tibial suture alter the outcome for dogs with cranial cruciate ligament insufficiency undergoing arthrotomy and caudal pole medial meniscectomy? Vet Comp Orthop Traumatol. 22(4):283–288. doi:10.3415/VCOT-08-03-0025.

Tivers MS, Mahoney P, Corr SA. 2008. Canine stifle positive contrast computed tomography arthrography for assessment of caudal horn meniscal injury: a cadaver study. Vet Surg. 37(3):269–277. doi:10.1111/j.1532-950X.2008.00376.x.

Torres de la Riva G, Hart BL, Farver TB, Oberbauer AM, Messam LLM, Willits N, Hart LA. 2013. Neutering dogs: effects on joint disorders and cancers in golden retrievers. PLoS One. 8(2):e55937. doi:10.1371/journal.pone.0055937.

Tuttle TA, Manley PA. 2009. Risk factors associated with fibular fracture after tibial plateau leveling osteotomy. Vet Surg. 38(3):355–360. doi:10.1111/j.1532-950X.2009.00504.x.

Vasseur PB. 1984. Clinical Results Following Nonoperative Management for Rupture of the Cranial Cruciate Ligament in Dogs. Vet Surg. 13(4):243–246. doi:https://doi.org/10.1111/j.1532-950X.1984.tb00801.x.

Vasseur PB, Arnoczky SP. 1981. Collateral ligaments of the canine stifle joint: anatomic and functional analysis. Am J Vet Res. 42(7):1133–1137.

Vasseur PB, Levy J, Dowd E, Eliot J. 1988. Surgical wound infection rates in dogs and cats. Data from a teaching hospital. Vet Surg. 17(2):60–64. doi:10.1111/j.1532-

950x.1988.tb00278.x.

Wallace AM, Addison ES, Smith BA, Radke H, Hobbs SJ. 2011. Modification of the cranial closing wedge ostectomy technique for the treatment of canine cruciate disease. Description and comparison with standard technique. Vet Comp Orthop Traumatol. 24(6):457–462. doi:10.3415/VCOT-10-11-0159.

Warzee CC, Dejardin LM, Arnoczky SP, Perry RL. 2001. Effect of tibial plateau leveling on cranial and caudal tibial thrusts in canine cranial cruciate-deficient stifles: an in vitro experimental study. Vet Surg. 30(3):278–286. doi:10.1053/jvet.2001.21400.

Whitehair JG, Vasseur PB, Willits NH. 1993. Epidemiology of cranial cruciate ligament rupture in dogs. J Am Vet Med Assoc. 203(7):1016–1019.

Whitney WO. 2003. Arthroscopically assisted surgery of the stifle joint. In: Brian Beale, Hulse D, Schulz K, Whitney W, editors. Small Animal Arthroscopy. WB Saunders, Philadelphia. p. 117–157.

Wilke VL, Conzemius MG, Besancon MF, Evans RB, Ritter M. 2002. Comparison of tibial plateau angle between clinically normal Greyhounds and Labrador Retrievers with and without rupture of the cranial cruciate ligament. J Am Vet Med Assoc. 221(10):1426–1429. doi:10.2460/javma.2002.221.1426.

Wilke VL, Conzemius MG, Kinghorn BP, Macrossan PE, Cai W, Rothschild MF. 2006. Inheritance of rupture of the cranial cruciate ligament in Newfoundlands. J Am Vet Med Assoc. 228(1):61–64. doi:10.2460/javma.228.1.61.

Wilke VL, Zhang S, Evans RB, Conzemius MG, Rothschild MF. 2009. Identification of chromosomal regions associated with cranial cruciate ligament rupture in a population of Newfoundlands. Am J Vet Res. 70(8):1013–1017. doi:10.2460/ajvr.70.8.1013.

Windolf M, Leitner M, Schwieger K, Pearce SG, Zeiter S, Schneider E, Johnson KA. 2008. Accuracy of fragment positioning after TPLO and effect on biomechanical stability. Vet Surg. 37(4):366–373. doi:10.1111/j.1532-950X.2008.00390.x.

Witsberger TH, Villamil JA, Schultz LG, Hahn AW, Cook JL. 2008. Prevalence of and risk factors for hip dysplasia and cranial cruciate ligament deficiency in dogs. J Am Vet Med Assoc. 232(12):1818–1824. doi:10.2460/javma.232.12.1818.

Wolf RE, Scavelli TD, Hoelzler MG, Fulcher RP, Bastian RP. 2012. Surgical and postoperative complications associated with tibial tuberosity advancement for cranial cruciate ligament rupture in dogs: 458 cases (2007-2009). J Am Vet Med Assoc. 240(12):1481–1487. doi:10.2460/javma.240.12.1481.

Wucherer KL, Conzemius MG, Evans R, Wilke VL. 2013. Short-term and long-term outcomes for overweight dogs with cranial cruciate ligament rupture treated surgically or nonsurgically. J Am Vet Med Assoc. 242(10):1364–1372. doi:10.2460/javma.242.10.1364.

Yahia LH, Newman NM, St-Georges M. 1992. Innervation of the canine cruciate ligaments. A neurohistological study. Anat Histol Embryol. 21(1):1–8. doi:10.1111/j.1439-0264.1992.tb00313.x.